US009287095B2

(12) United States Patent
Nguyen et al.

(10) Patent No.: US 9,287,095 B2
(45) Date of Patent: Mar. 15, 2016

(54) **SEMICONDUCTOR SYSTEM ASSEMBLIES AND METHODS OF OPERATION**

(71) Applicant: **Applied Materials, Inc.**, Santa Clara, CA (US)

(72) Inventors: **Andrew Nguyen**, San Jose, CA (US); **Kartik Ramaswamy**, San Jose, CA (US); **Srinivas Nemani**, Sunnyvale, CA (US); **Bradley Howard**, Pleasanton, CA (US); **Yogananda Sarode Vishwanath**, Karnataka (IN)

(73) Assignee: **Applied Materials, Inc.**, Santa Clara, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/108,692**

(22) Filed: **Dec. 17, 2013**

(65) **Prior Publication Data**

US 2015/0170924 A1 Jun. 18, 2015

(51) **Int. Cl.**

H01J 37/32	(2006.01)
H01L 21/3065	(2006.01)
H01L 21/311	(2006.01)
H01L 21/3213	(2006.01)

(52) **U.S. Cl.**

CPC ***H01J 37/32357*** (2013.01); ***H01J 37/3244*** (2013.01); ***H01J 37/32449*** (2013.01); ***H01J 37/32568*** (2013.01); ***H01L 21/3065*** (2013.01); *H01J 37/32091* (2013.01); *H01J 37/32532* (2013.01); *H01L 21/31116* (2013.01); *H01L 21/31138* (2013.01); *H01L 21/32136* (2013.01)

(58) **Field of Classification Search**

CPC C23C 16/45512

USPC .... 118/715, 722, 723 R, 723 E, 723 I, 118/723 IR, 723 MW, 723 ME; 156/345.33–345.35; 315/111.21

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,369,620	A	2/1945	Sullivan et al.
3,451,840	A	6/1969	Hough
3,937,857	A	2/1976	Brummett et al.
3,969,077	A	7/1976	Hill

(Continued)

FOREIGN PATENT DOCUMENTS

AL	0 658 928 A1	6/1995
CN	1375575	10/2002

(Continued)

OTHER PUBLICATIONS

Abe et al., "Developments of plasma etching technology for fabricating semiconductor devices," Jpn. J. Appl. Phys., vol. 47, No. 3R, Mar. 2008, 21 pgs.

(Continued)

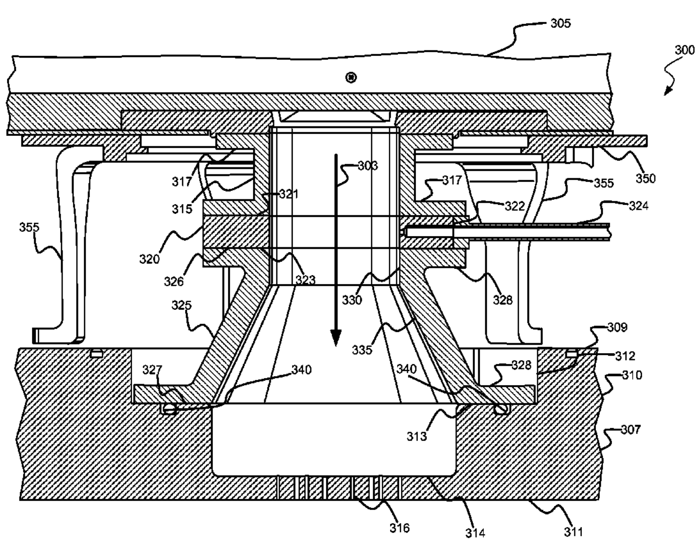
Primary Examiner — Maureen Passey

(74) *Attorney, Agent, or Firm* — Kilpatrick Townsend & Stockton LLP

(57) **ABSTRACT**

An exemplary semiconductor processing system may include a remote plasma source coupled with a processing chamber having a top plate. An inlet assembly may be used to couple the remote plasma source with the top plate and may include a mounting assembly, which in embodiments may include at least two components. The inlet assembly may further include a precursor distribution assembly defining a plurality of distribution channels fluidly coupled with an injection port.

17 Claims, 5 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

4,006,047	A	2/1977	Brummett et al.
4,209,357	A	6/1980	Gorin et al.
4,214,946	A	7/1980	Forget et al.
4,232,060	A	11/1980	Mallory, Jr.
4,234,628	A	11/1980	DuRose
4,265,943	A	5/1981	Goldstein et al.
4,361,441	A	11/1982	Tylko
4,364,803	A	12/1982	Nidola et al.
4,368,223	A	1/1983	Kobayashi et al.
4,397,812	A	8/1983	Mallory, Jr.
4,468,413	A	8/1984	Bachmann
4,565,601	A	1/1986	Kakehi et al.
4,571,819	A	2/1986	Rogers et al.
4,579,618	A	4/1986	Celestino et al.
4,585,920	A	4/1986	Hoog et al.
4,625,678	A	12/1986	Shloya et al.
4,632,857	A	12/1986	Mallory, Jr.
4,656,052	A	4/1987	Satou et al.
4,690,746	A	9/1987	McInerney et al.
4,714,520	A	12/1987	Gwozdz
4,715,937	A	12/1987	Moslehi et al.
4,749,440	A	6/1988	Blackwood et al.
4,753,898	A	6/1988	Parrillo et al.
4,786,360	A	11/1988	Cote et al.
4,793,897	A	12/1988	Dunfield et al.
4,807,016	A	2/1989	Douglas
4,810,520	A	3/1989	Wu
4,816,638	A	3/1989	Ukai et al.
4,820,377	A	4/1989	Davis et al.
4,851,370	A	7/1989	Doklan et al.
4,857,140	A	8/1989	Loewenstein
4,865,685	A	9/1989	Palmour
4,868,071	A	9/1989	Walsh et al.
4,872,947	A	10/1989	Wang et al.
4,878,994	A	11/1989	Jucha et al.
4,886,570	A	12/1989	Davis et al.
4,892,753	A	1/1990	Wang et al.
4,894,352	A	1/1990	Lane et al.
4,904,341	A	2/1990	Blaugher et al.
4,904,621	A	2/1990	Loewenstein et al.
4,913,929	A	4/1990	Moslehi et al.
4,951,601	A	8/1990	Maydan et al.
4,960,488	A	10/1990	Law et al.
4,980,018	A	12/1990	Mu et al.
4,981,551	A	1/1991	Palmour
4,985,372	A	1/1991	Narita et al.
4,991,542	A	2/1991	Kohmura et al.
4,992,136	A	2/1991	Tachi et al.
4,994,404	A	2/1991	Sheng et al.
5,000,113	A	3/1991	Wang et al.
5,013,691	A	5/1991	Lory et al.
5,028,565	A	7/1991	Chang
5,030,319	A	7/1991	Nishino et al.
5,061,838	A	10/1991	Lane et al.
5,083,030	A	1/1992	Stavov
5,089,441	A	2/1992	Moslehi
5,089,442	A	2/1992	Olmer
5,147,692	A	9/1992	Bengston
5,156,881	A	10/1992	Okano et al.
5,180,435	A	1/1993	Markunas et al.
5,186,718	A	2/1993	Tepman et al.
5,188,706	A	2/1993	Hori et al.
5,198,034	A	3/1993	deBoer et al.
5,203,911	A	4/1993	Sricharoenchalkit et al.
5,215,787	A	6/1993	Homma
5,228,501	A	7/1993	Tepman et al.
5,231,690	A	7/1993	Soma et al.
5,235,139	A	8/1993	Bengston et al.
5,238,499	A	8/1993	van de Ven et al.
5,240,497	A	8/1993	Shacham et al.
5,248,527	A	9/1993	Uchida et al.
5,252,178	A	10/1993	Moslehi
5,266,157	A	11/1993	Kadomura
5,270,125	A	12/1993	America et al.
5,271,972	A	12/1993	Kwok et al.
5,275,977	A	1/1994	Otsubo et al.
5,279,865	A	1/1994	Chebi et al.
5,288,518	A	2/1994	Homma
5,290,382	A	3/1994	Zarowin et al.
5,300,463	A	4/1994	Cathey et al.
5,302,233	A	4/1994	Kim et al.
5,306,530	A	4/1994	Strongin et al.
5,314,724	A	5/1994	Tsukune et al.
5,316,804	A	5/1994	Tomikawa et al.
5,319,247	A	6/1994	Matsuura
5,326,427	A	7/1994	Jerbic
5,328,218	A	7/1994	Lowrey et al.
5,328,558	A	7/1994	Kawamura et al.
5,334,552	A	8/1994	Homma
5,345,999	A	9/1994	Hosokawa
5,352,636	A	10/1994	Beinglass
5,356,478	A	10/1994	Chen et al.
5,362,526	A	11/1994	Wang et al.
5,368,897	A	11/1994	Kurihara et al.
5,380,560	A	1/1995	Kaja et al.
5,382,311	A	1/1995	Ishikawa et al.
5,384,284	A	1/1995	Doan et al.
5,385,763	A	1/1995	Okano et al.
5,399,237	A	3/1995	Keswick et al.
5,399,529	A	3/1995	Homma
5,403,434	A	4/1995	Moslehi
5,413,670	A	5/1995	Langan et al.
5,413,967	A	5/1995	Matsuda et al.
5,415,890	A	5/1995	Kloiber et al.
5,416,048	A	5/1995	Blalock et al.
5,420,075	A	5/1995	Homma et al.
5,429,995	A	7/1995	Nishiyama et al.
5,439,553	A	8/1995	Grant et al.
5,451,259	A	9/1995	Krogh
5,468,342	A	11/1995	Nulty et al.
5,474,589	A	12/1995	Ohga et al.
5,478,403	A	12/1995	Shinigawa et al.
5,478,462	A	12/1995	Walsh
5,483,920	A	1/1996	Pryor
5,500,249	A	3/1996	Telford et al.
5,505,816	A	4/1996	Barnes et al.
5,510,216	A	4/1996	Calabrese et al.
5,516,367	A	5/1996	Lei et al.
5,518,962	A	5/1996	Murao
5,531,835	A	7/1996	Fodor et al.
5,534,070	A	7/1996	Okamura et al.
5,536,360	A	7/1996	Nguyen et al.
5,549,780	A	8/1996	Koinuma et al.
5,558,717	A	9/1996	Zhao et al.
5,560,779	A	10/1996	Knowles et al.
5,563,105	A	10/1996	Dobuzinsky et al.
5,567,243	A	10/1996	Foster et al.
5,571,576	A	11/1996	Qian et al.
5,578,130	A	11/1996	Hayashi et al.
5,578,161	A	11/1996	Auda
5,580,421	A	12/1996	Hiatt et al.
5,591,269	A	1/1997	Arami et al.
5,599,740	A	2/1997	Jang et al.
5,616,518	A	4/1997	Foo et al.
5,624,582	A	4/1997	Cain
5,626,922	A	5/1997	Miyanaga et al.
5,628,829	A	5/1997	Foster et al.
5,635,086	A	6/1997	Warren, Jr.
5,645,645	A	7/1997	Zhang et al.
5,648,125	A	7/1997	Cane
5,648,175	A	7/1997	Russell et al.
5,656,093	A	8/1997	Burkhart et al.
5,661,093	A	8/1997	Ravi et al.
5,674,787	A	10/1997	Zhao et al.
5,676,758	A	10/1997	Hasgawa et al.
5,679,606	A	10/1997	Wang et al.
5,685,946	A	11/1997	Fathauer et al.
5,688,331	A	11/1997	Aruga et al.
5,695,810	A	12/1997	Dubin et al.
5,712,185	A	1/1998	Tsai et al.
5,716,500	A	2/1998	Bardos et al.
5,716,506	A	2/1998	Maclay et al.
5,719,085	A	2/1998	Moon et al.
5,733,816	A	3/1998	Iyer et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,747,373	A	5/1998	Yu
5,755,859	A	5/1998	Brusic et al.
5,756,400	A	5/1998	Ye et al.
5,756,402	A	5/1998	Jimbo et al.
5,772,770	A	6/1998	Suda et al.
5,781,693	A	7/1998	Ballance et al.
5,786,276	A	7/1998	Brooks et al.
5,789,300	A	8/1998	Fulford
5,800,686	A	9/1998	Littau et al.
5,804,259	A	9/1998	Robles
5,812,403	A	9/1998	Fong et al.
5,814,365	A	9/1998	Mahawili
5,820,723	A	10/1998	Benjamin et al.
5,824,599	A	10/1998	Schacham-Diamand et al.
5,830,805	A	11/1998	Schacham-Diamand et al.
5,838,055	A	11/1998	Kleinhenz et al.
5,843,538	A	12/1998	Ehrsam et al.
5,843,847	A	12/1998	Pu et al.
5,844,195	A	12/1998	Fairbairn et al.
5,846,332	A	12/1998	Zhao et al.
5,846,375	A	12/1998	Gilchrist et al.
5,846,598	A	12/1998	Semkow et al.
5,849,639	A	12/1998	Molloy et al.
5,850,105	A	12/1998	Dawson et al.
5,855,681	A	1/1999	Maydan et al.
5,856,240	A	1/1999	Sinha et al.
5,858,876	A	1/1999	Chew
5,866,483	A	2/1999	Shiau et al.
5,872,052	A	2/1999	Iyer
5,872,058	A	2/1999	Van Cleemput et al.
5,882,424	A	3/1999	Taylor et al.
5,882,786	A	3/1999	Nassau et al.
5,883,012	A	3/1999	Chiou
5,885,404	A	3/1999	Kim et al.
5,885,749	A	3/1999	Huggins et al.
5,888,906	A	3/1999	Sandhu et al.
5,891,349	A	4/1999	Tobe et al.
5,891,513	A	4/1999	Dubin et al.
5,897,751	A	4/1999	Makowiecki
5,899,752	A	5/1999	Hey et al.
5,904,827	A	5/1999	Reynolds
5,907,790	A	5/1999	Kellam
5,910,340	A	6/1999	Uchida et al.
5,913,140	A	6/1999	Roche et al.
5,913,147	A	6/1999	Dubin et al.
5,915,190	A	6/1999	Pirkle
5,918,116	A	6/1999	Chittipeddi
5,920,792	A	7/1999	Lin
5,932,077	A	8/1999	Reynolds
5,933,757	A	8/1999	Yoshikawa et al.
5,935,334	A	8/1999	Fong et al.
5,937,323	A	8/1999	Orczyk et al.
5,939,831	A	8/1999	Fong et al.
5,942,075	A	8/1999	Nagahata et al.
5,944,902	A	8/1999	Redeker et al.
5,951,601	A	9/1999	Lesinski et al.
5,951,776	A	9/1999	Selyutin et al.
5,951,896	A	9/1999	Mahawili
5,953,591	A	9/1999	Ishihara et al.
5,953,635	A	9/1999	Andideh
5,968,610	A	10/1999	Liu et al.
5,969,422	A	10/1999	Ting et al.
5,976,327	A	11/1999	Tanaka
5,990,000	A	11/1999	Hong et al.
5,990,013	A	11/1999	Berenguer et al.
5,993,916	A	11/1999	Zhao et al.
6,004,884	A	12/1999	Abraham
6,007,635	A	12/1999	Mahawili
6,010,962	A	1/2000	Liu et al.
6,013,191	A	1/2000	Nasser-Faili et al.
6,013,584	A	1/2000	M'Saad
6,015,724	A	1/2000	Yamazaki et al.
6,015,747	A	1/2000	Lopatin et al.
6,020,271	A	2/2000	Yanagida
6,030,666	A	2/2000	Lam et al.
6,030,881	A	2/2000	Papasouliotis et al.
6,035,101	A	3/2000	Sajoto et al.
6,037,018	A	3/2000	Jang et al.
6,037,266	A	3/2000	Tao et al.
6,039,851	A	3/2000	Iyer
6,053,982	A	4/2000	Halpin et al.
6,059,643	A	5/2000	Hu et al.
6,063,683	A	5/2000	Wu et al.
6,063,712	A	5/2000	Gilton et al.
6,065,424	A	5/2000	Shacham-Diamand et al.
6,072,147	A	6/2000	Koshiishi
6,072,227	A	6/2000	Yau et al.
6,077,780	A	6/2000	Dubin
6,080,529	A	6/2000	Ye et al.
6,083,344	A	7/2000	Hanawa et al.
6,083,844	A	7/2000	Bui-Le et al.
6,086,677	A	7/2000	Umotoy et al.
6,087,278	A	7/2000	Kim et al.
6,090,212	A	7/2000	Mahawili
6,093,457	A	7/2000	Okumura
6,093,594	A	7/2000	Yeap et al.
6,099,697	A	8/2000	Hausmann
6,107,199	A	8/2000	Allen et al.
6,110,530	A	8/2000	Chen et al.
6,110,836	A	8/2000	Cohen et al.
6,110,838	A	8/2000	Loewenstein
6,113,771	A	9/2000	Landau et al.
6,117,245	A	9/2000	Mandrekar et al.
6,136,163	A	10/2000	Cheung et al.
6,136,685	A	10/2000	Narwankar et al.
6,136,693	A	10/2000	Chan et al.
6,140,234	A	10/2000	Uzoh et al.
6,144,099	A	11/2000	Lopatin et al.
6,147,009	A	11/2000	Grill et al.
6,149,828	A	11/2000	Vaartstra
6,150,628	A	11/2000	Smith et al.
6,153,935	A	11/2000	Edelstein et al.
6,165,912	A	12/2000	McConnell et al.
6,167,834	B1	1/2001	Wang et al.
6,169,021	B1	1/2001	Akram et al.
6,170,428	B1	1/2001	Redeker et al.
6,171,661	B1	1/2001	Zheng et al.
6,174,450	B1	1/2001	Patrick et al.
6,174,812	B1	1/2001	Hsuing et al.
6,176,198	B1	1/2001	Kao et al.
6,177,245	B1	1/2001	Ward et al.
6,179,924	B1	1/2001	Zhao et al.
6,180,523	B1	1/2001	Lee et al.
6,182,602	B1	2/2001	Redeker et al.
6,184,121	B1	2/2001	Buchwalter et al.
6,189,483	B1	2/2001	Ishikawa et al.
6,190,233	B1	2/2001	Hong et al.
6,191,026	B1	2/2001	Rana et al.
6,194,038	B1	2/2001	Rossman
6,197,181	B1	3/2001	Chen
6,197,364	B1	3/2001	Paunovic et al.
6,197,680	B1	3/2001	Lin et al.
6,197,688	B1	3/2001	Simpson
6,197,705	B1	3/2001	Vassiliev
6,203,863	B1	3/2001	Liu et al.
6,204,200	B1	3/2001	Shieh et al.
6,210,486	B1	4/2001	Mizukami et al.
6,217,658	B1	4/2001	Orczyk et al.
6,228,233	B1	5/2001	Lakshmikanthan et al.
6,228,751	B1	5/2001	Yamazaki et al.
6,228,758	B1	5/2001	Pellerin et al.
6,235,643	B1	5/2001	Mui et al.
6,237,527	B1	5/2001	Kellerman et al.
6,238,513	B1	5/2001	Arnold et al.
6,238,582	B1	5/2001	Williams et al.
6,241,845	B1	6/2001	Gadgil et al.
6,242,349	B1	6/2001	Nogami et al.
6,245,396	B1	6/2001	Nogami
6,245,670	B1	6/2001	Cheung et al.
6,251,236	B1	6/2001	Stevens
6,251,802	B1	6/2001	Moore et al.
6,258,220	B1	7/2001	Dordi et al.
6,258,223	B1	7/2001	Cheung et al.
6,258,270	B1	7/2001	Hilgendorff et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,261,637	B1	7/2001	Oberle
6,277,733	B1	8/2001	Smith
6,277,752	B1	8/2001	Chen
6,277,763	B1	8/2001	Kugimiya et al.
6,281,072	B1	8/2001	Li et al.
6,281,135	B1	8/2001	Han et al.
6,291,282	B1	9/2001	Wilk et al.
6,291,348	B1	9/2001	Lopatin et al.
6,303,418	B1	10/2001	Cha et al.
6,312,554	B1	11/2001	Ye
6,312,995	B1	11/2001	Yu
6,313,035	B1	11/2001	Sandhu et al.
6,319,387	B1	11/2001	Krishnamoorthy et al.
6,322,716	B1	11/2001	Qiao et al.
6,323,128	B1	11/2001	Sambucetti et al.
6,335,261	B1	1/2002	Natzle et al.
6,335,288	B1	1/2002	Kwan et al.
6,340,435	B1	1/2002	Bjorkman et al.
6,342,733	B1	1/2002	Hu et al.
RE37,546	E	2/2002	Mahawili
6,344,410	B1	2/2002	Lopatin et al.
6,350,320	B1	2/2002	Sherstinsky et al.
6,350,697	B1	2/2002	Richardson
6,351,013	B1	2/2002	Luning et al.
6,352,081	B1	3/2002	Lu et al.
6,355,573	B1	3/2002	Okumura
6,364,949	B1	4/2002	Or et al.
6,364,954	B2	4/2002	Umotoy et al.
6,364,957	B1	4/2002	Schneider et al.
6,372,657	B1	4/2002	Hineman et al.
6,375,748	B1	4/2002	Yudovsky et al.
6,376,386	B1	4/2002	Oshima
6,379,575	B1	4/2002	Yin et al.
6,383,951	B1	5/2002	Li
6,387,207	B1	5/2002	Janakiraman et al.
6,391,753	B1	5/2002	Yu
6,395,150	B1	5/2002	Van Cleemput et al.
6,403,491	B1	6/2002	Liu et al.
6,415,736	B1	7/2002	Hao et al.
6,416,647	B1	7/2002	Dordi et al.
6,416,874	B1	7/2002	McAneney et al.
6,423,284	B1	7/2002	Arno
6,427,623	B2	8/2002	Ko
6,432,819	B1	8/2002	Pavate et al.
6,432,831	B2	8/2002	Dhindsa et al.
6,436,193	B1	8/2002	Kasai et al.
6,436,816	B1	8/2002	Lee et al.
6,440,863	B1	8/2002	Tsai et al.
6,441,492	B1	8/2002	Cunningham
6,446,572	B1	9/2002	Brcka
6,448,537	B1	9/2002	Nering
6,458,718	B1	10/2002	Todd
6,461,974	B1	10/2002	Ni et al.
6,462,371	B1	10/2002	Weimer et al.
6,465,366	B1	10/2002	Nemani et al.
6,477,980	B1	11/2002	White et al.
6,479,373	B2	11/2002	Dreybrodt et al.
6,488,984	B1	12/2002	Wada et al.
6,494,959	B1	12/2002	Samoilov et al.
6,499,425	B1	12/2002	Sandhu et al.
6,500,728	B1	12/2002	Wang
6,503,843	B1	1/2003	Xia et al.
6,506,291	B2	1/2003	Tsai et al.
6,509,623	B2	1/2003	Zhao
6,516,815	B1	2/2003	Stevens et al.
6,518,548	B2	2/2003	Sugaya et al.
6,527,968	B1	3/2003	Wang et al.
6,528,409	B1	3/2003	Lopatin et al.
6,531,377	B2	3/2003	Knorr et al.
6,537,733	B2	3/2003	Campana et al.
6,541,397	B1	4/2003	Bencher
6,541,671	B1	4/2003	Martinez et al.
6,544,340	B2	4/2003	Yudovsky
6,547,977	B1	4/2003	Yan et al.
6,551,924	B1	4/2003	Dalton et al.
6,565,729	B2	5/2003	Chen et al.
6,569,773	B1	5/2003	Gellrich et al.
6,573,030	B1	6/2003	Fairbairn et al.
6,573,606	B2	6/2003	Sambucetti et al.
6,586,163	B1	7/2003	Okabe et al.
6,596,599	B1	7/2003	Guo
6,596,602	B2	7/2003	Iizuka et al.
6,596,654	B1	7/2003	Bayman et al.
6,602,434	B1	8/2003	Hung et al.
6,603,269	B1	8/2003	Vo et al.
6,605,874	B2	8/2003	Leu et al.
6,616,967	B1	9/2003	Test
6,627,532	B1	9/2003	Gaillard et al.
6,635,578	B1	10/2003	Xu et al.
6,638,810	B2	10/2003	Bakli et al.
6,645,301	B2	11/2003	Sainty et al.
6,645,550	B1	11/2003	Cheung et al.
6,656,831	B1	12/2003	Lee et al.
6,656,837	B2	12/2003	Xu et al.
6,663,715	B1	12/2003	Yuda et al.
6,677,242	B1	1/2004	Liu et al.
6,677,247	B2	1/2004	Yuan et al.
6,679,981	B1	1/2004	Pan et al.
6,713,356	B1	3/2004	Skotnicki et al.
6,713,835	B1	3/2004	Horak et al.
6,717,189	B2	4/2004	Inoue et al.
6,720,213	B1	4/2004	Gambino et al.
6,740,585	B2	5/2004	Yoon et al.
6,740,977	B2	5/2004	Ahn et al.
6,743,473	B1	6/2004	Parkhe et al.
6,743,732	B1	6/2004	Lin et al.
6,756,235	B1	6/2004	Liu et al.
6,759,261	B2	7/2004	Shimokohbe et al.
6,762,127	B2	7/2004	Boiteux et al.
6,762,435	B2	7/2004	Towle
6,764,958	B1	7/2004	Nemani et al.
6,765,273	B1	7/2004	Chau et al.
6,767,834	B2	7/2004	Chung et al.
6,772,827	B2	8/2004	Keller et al.
6,794,290	B1	9/2004	Papasouliotis et al.
6,794,311	B2	9/2004	Huang et al.
6,796,314	B1	9/2004	Graff et al.
6,797,189	B2	9/2004	Hung et al.
6,800,830	B2	10/2004	Mahawili
6,802,944	B2	10/2004	Ahmad et al.
6,808,564	B2	10/2004	Dietze
6,808,748	B2	10/2004	Kapoor et al.
6,821,571	B2	11/2004	Huang
6,823,589	B2	11/2004	White et al.
6,830,624	B2	12/2004	Janakiraman et al.
6,835,995	B2	12/2004	Li
6,846,745	B1	1/2005	Papasouliotis et al.
6,852,550	B2	2/2005	Tuttle et al.
6,858,153	B2	2/2005	Bjorkman et al.
6,861,097	B1	3/2005	Goosey et al.
6,861,332	B2	3/2005	Park et al.
6,867,141	B2	3/2005	Jung et al.
6,869,880	B2	3/2005	Krishnaraj et al.
6,875,280	B2	4/2005	Ikeda et al.
6,878,206	B2	4/2005	Tzu et al.
6,879,981	B2	4/2005	Rothschild et al.
6,886,491	B2	5/2005	Kim et al.
6,892,669	B2	5/2005	Xu et al.
6,893,967	B1	5/2005	Wright et al.
6,897,532	B1	5/2005	Schwarz et al.
6,903,031	B2	6/2005	Karim et al.
6,903,511	B2	6/2005	Chistyakov
6,908,862	B2	6/2005	Li et al.
6,911,112	B2	6/2005	An
6,911,401	B2	6/2005	Khandan et al.
6,921,556	B2	7/2005	Shimizu et al.
6,924,191	B2	8/2005	Liu et al.
6,930,047	B2	8/2005	Yamazaki
6,942,753	B2	9/2005	Choi et al.
6,946,033	B2	9/2005	Tsuel et al.
6,951,821	B2	10/2005	Hamelin et al.
6,958,175	B2	10/2005	Sakamoto et al.
6,958,286	B2	10/2005	Chen et al.
6,974,780	B2	12/2005	Schuegraf

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,995,073	B2	2/2006	Liou
7,017,269	B2	3/2006	White et al.
7,018,941	B2	3/2006	Cui et al.
7,030,034	B2	4/2006	Fucsko et al.
7,049,200	B2	5/2006	Arghavani et al.
7,071,532	B2	7/2006	Geffken et al.
7,078,312	B1	7/2006	Sutanto et al.
7,081,414	B2	7/2006	Zhang et al.
7,084,070	B1	8/2006	Lee et al.
7,115,525	B2	10/2006	Abatchev et al.
7,122,949	B2	10/2006	Strikovski
7,145,725	B2	12/2006	Hasel et al.
7,148,155	B1	12/2006	Tarafdar et al.
7,166,233	B2	1/2007	Johnson et al.
7,183,214	B2	2/2007	Nam et al.
7,196,342	B2	3/2007	Ershov et al.
7,205,240	B2	4/2007	Karim et al.
7,223,701	B2	5/2007	Min et al.
7,226,805	B2	6/2007	Hallin et al.
7,235,137	B2	6/2007	Kitayama et al.
7,252,716	B2	8/2007	Kim et al.
7,253,123	B2	8/2007	Arghavani et al.
7,256,370	B2	8/2007	Guiver
7,288,482	B2	10/2007	Panda et al.
7,341,633	B2	3/2008	Lubomirsky et al.
7,358,192	B2	4/2008	Merry et al.
7,365,016	B2	4/2008	Ouellet et al.
7,390,710	B2	6/2008	Derderian et al.
7,396,480	B2	7/2008	Kao et al.
7,416,989	B1	8/2008	Liu et al.
7,465,358	B2	12/2008	Weidman et al.
7,468,319	B2	12/2008	Lee
7,484,473	B2	2/2009	Keller et al.
7,488,688	B2	2/2009	Chung et al.
7,494,545	B2	2/2009	Lam et al.
7,553,756	B2	6/2009	Hayashi et al.
7,575,007	B2	8/2009	Tang et al.
7,581,511	B2	9/2009	Mardian et al.
7,604,708	B2	10/2009	Wood et al.
7,628,897	B2	12/2009	Mungekar et al.
7,682,518	B2	3/2010	Chandrachood et al.
7,708,859	B2	5/2010	Huang et al.
7,709,396	B2	5/2010	Bencher et al.
7,722,925	B2	5/2010	White et al.
7,723,221	B2	5/2010	Hayashi
7,749,326	B2	7/2010	Kim et al.
7,785,672	B2	8/2010	Choi et al.
7,790,634	B2	9/2010	Munro et al.
7,806,078	B2	10/2010	Yoshida
7,807,578	B2	10/2010	Bencher et al.
7,825,038	B2	11/2010	Ingle et al.
7,837,828	B2	11/2010	Ikeda et al.
7,871,926	B2	1/2011	Xia et al.
7,910,491	B2	3/2011	Soo Kwon et al.
7,915,139	B1	3/2011	Lang et al.
7,932,181	B2	4/2011	Singh et al.
7,939,422	B2	5/2011	Ingle et al.
7,968,441	B2	6/2011	Xu
7,976,631	B2	7/2011	Burrows
7,981,806	B2	7/2011	Jung
7,989,365	B2	8/2011	Park et al.
8,008,166	B2	8/2011	Sanchez et al.
8,058,179	B1	11/2011	Draeger et al.
8,071,482	B2	12/2011	Kawada
8,074,599	B2	12/2011	Choi et al.
8,076,198	B2	12/2011	Lee et al.
8,083,853	B2	12/2011	Choi et al.
8,119,530	B2	2/2012	Hori et al.
8,133,349	B1	3/2012	Panagopoulos
8,183,134	B2	5/2012	Wu
8,187,486	B1	5/2012	Liu et al.
8,211,808	B2	7/2012	Sapre et al.
8,298,627	B2	10/2012	Minami et al.
8,309,440	B2	11/2012	Sanchez et al.
8,313,610	B2	11/2012	Dhindsa
8,328,939	B2	12/2012	Choi et al.
8,368,308	B2	2/2013	Banna et al.
8,435,902	B2	5/2013	Tang et al.
8,475,674	B2	7/2013	Thadani et al.
8,491,805	B2	7/2013	Kushibiki et al.
8,501,629	B2	8/2013	Tang et al.
8,506,713	B2	8/2013	Takagi
8,512,509	B2	8/2013	Bera et al.
8,623,148	B2	1/2014	Mitchell et al.
8,623,471	B2	1/2014	Tyler et al.
8,642,481	B2	2/2014	Wang et al.
8,679,982	B2	3/2014	Wang et al.
8,679,983	B2	3/2014	Wang et al.
8,741,778	B2	6/2014	Yang et al.
8,747,680	B1	6/2014	Deshpande
8,765,574	B2	7/2014	Zhang et al.
8,771,536	B2	7/2014	Zhang et al.
8,771,539	B2	7/2014	Zhang et al.
8,772,888	B2	7/2014	Jung et al.
8,778,079	B2	7/2014	Begarney et al.
8,801,952	B1	8/2014	Wang et al.
8,808,563	B2	8/2014	Wang et al.
8,846,163	B2	9/2014	Kao et al.
8,895,449	B1	11/2014	Zhu et al.
8,900,364	B2	12/2014	Wright
8,921,234	B2	12/2014	Liu et al.
8,927,390	B2	1/2015	Sapre et al.
8,951,429	B1	2/2015	Liu et al.
8,956,980	B1	2/2015	Chen et al.
8,969,212	B2	3/2015	Ren et al.
8,980,005	B2	3/2015	Carlson et al.
8,980,758	B1	3/2015	Ling et al.
8,980,763	B2	3/2015	Wang et al.
8,992,723	B2	3/2015	Sorensen et al.
8,999,839	B2	4/2015	Su et al.
8,999,856	B2	4/2015	Zhang et al.
9,012,302	B2	4/2015	Sapre et al.
9,017,481	B1	4/2015	Pettinger et al.
9,023,732	B2	5/2015	Wang et al.
9,023,734	B2	5/2015	Chen et al.
9,034,770	B2	5/2015	Park et al.
9,040,422	B2	5/2015	Wang et al.
9,064,815	B2	6/2015	Zhang et al.
9,064,816	B2	6/2015	Kim et al.
9,072,158	B2	6/2015	Ikeda et al.
9,093,371	B2	7/2015	Wang et al.
9,093,390	B2	7/2015	Wang et al.
9,111,877	B2	8/2015	Chen et al.
9,114,438	B2	8/2015	Hoinkis et al.
9,117,855	B2	8/2015	Cho et al.
9,132,436	B2	9/2015	Liang et al.
9,136,273	B1	9/2015	Purayath et al.
9,144,147	B2	9/2015	Yang et al.
9,153,442	B2	10/2015	Wang et al.
9,159,606	B1	10/2015	Purayath et al.
9,165,786	B1	10/2015	Purayath et al.
9,184,055	B2	11/2015	Wang et al.
2001/0008803	A1	7/2001	Takamatsu et al.
2001/0015261	A1	8/2001	Kobayashi et al.
2001/0028093	A1	10/2001	Yamazaki et al.
2001/0028922	A1	10/2001	Sandhu
2001/0030366	A1	10/2001	Nakano et al.
2001/0034121	A1	10/2001	Fu et al.
2001/0036706	A1	11/2001	Kitamura
2001/0037856	A1	11/2001	Park
2001/0041444	A1	11/2001	Shields et al.
2001/0047760	A1	12/2001	Mosiehl
2001/0053585	A1	12/2001	Kikuchi et al.
2001/0054381	A1	12/2001	Umotoy et al.
2001/0055842	A1	12/2001	Uh et al.
2002/0000202	A1	1/2002	Yuda et al.
2002/0011210	A1	1/2002	Satoh et al.
2002/0016080	A1	2/2002	Khan et al.
2002/0016085	A1	2/2002	Huang et al.
2002/0028582	A1	3/2002	Nallan et al.
2002/0028585	A1	3/2002	Chung et al.
2002/0029747	A1	3/2002	Powell et al.
2002/0033233	A1	3/2002	Savas
2002/0036143	A1	3/2002	Segawa et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2002/0040764	A1	4/2002	Kwan et al.	
2002/0040766	A1	4/2002	Takahashi	
2002/0045966	A1	4/2002	Lee et al.	
2002/0054962	A1	5/2002	Huang	
2002/0069820	A1	6/2002	Yudovsky	
2002/0070414	A1	6/2002	Drescher et al.	
2002/0074573	A1	6/2002	Takeuchi et al.	
2002/0090781	A1	7/2002	Skotnicki et al.	
2002/0098681	A1	7/2002	Hu et al.	
2002/0124867	A1	9/2002	Kim et al.	
2002/0129769	A1	9/2002	Kim et al.	
2002/0153808	A1	10/2002	Skotnicki et al.	
2002/0164885	A1	11/2002	Lill et al.	
2002/0177322	A1	11/2002	Li et al.	
2002/0187280	A1	12/2002	Johnson et al.	
2002/0187655	A1	12/2002	Tan et al.	
2002/0197823	A1	12/2002	Yoo et al.	
2003/0003757	A1	1/2003	Nallan et al.	
2003/0010645	A1	1/2003	Ting et al.	
2003/0019428	A1	1/2003	Ku et al.	
2003/0019580	A1	1/2003	Strang	
2003/0029566	A1	2/2003	Roth	
2003/0029715	A1	2/2003	Yu et al.	
2003/0032284	A1	2/2003	Enomoto et al.	
2003/0038127	A1	2/2003	Liu et al.	
2003/0038305	A1	2/2003	Wasshuber	
2003/0054608	A1	3/2003	Tseng et al.	
2003/0072639	A1	4/2003	White et al.	
2003/0075808	A1	4/2003	Inoue et al.	
2003/0077909	A1	4/2003	Jiwari	
2003/0079686	A1	5/2003	Chen et al.	
2003/0087531	A1	5/2003	Kang et al.	
2003/0091938	A1	5/2003	Fairbairn et al.	
2003/0098125	A1	5/2003	An	
2003/0109143	A1	6/2003	Hsieh et al.	
2003/0116087	A1	6/2003	Nguyen et al.	
2003/0116439	A1	6/2003	Seo et al.	
2003/0121608	A1	7/2003	Chen et al.	
2003/0124465	A1	7/2003	Lee et al.	
2003/0124842	A1	7/2003	Hytros et al.	
2003/0127740	A1	7/2003	Hsu et al.	
2003/0129106	A1	7/2003	Sorensen et al.	
2003/0129827	A1	7/2003	Lee et al.	
2003/0132319	A1	7/2003	Hytros et al.	
2003/0140844	A1	7/2003	Maa et al.	
2003/0148035	A1	8/2003	Lingampalli	
2003/0159307	A1	8/2003	Sago et al.	
2003/0173333	A1	9/2003	Wang et al.	
2003/0173347	A1	9/2003	Guiver	
2003/0173675	A1	9/2003	Watanabe	
2003/0181040	A1	9/2003	Ivanov et al.	
2003/0183244	A1	10/2003	Rossman	
2003/0190426	A1	10/2003	Padhi et al.	
2003/0199170	A1	10/2003	Li	
2003/0205329	A1	11/2003	Gujer et al.	
2003/0215963	A1	11/2003	AmRhein et al.	
2003/0221780	A1	12/2003	Lei et al.	
2003/0224217	A1	12/2003	Byun et al.	
2003/0224617	A1	12/2003	Baek et al.	
2004/0005726	A1	1/2004	Huang	
2004/0020601	A1	2/2004	Zhao et al.	
2004/0026371	A1	2/2004	Nguyen et al.	
2004/0033678	A1	2/2004	Arghavani et al.	
2004/0050328	A1	3/2004	Kumagai et al.	
2004/0058293	A1	3/2004	Nguyen et al.	
2004/0069225	A1	4/2004	Fairbairn et al.	
2004/0070346	A1	4/2004	Choi	
2004/0072446	A1	4/2004	Liu et al.	
2004/0092063	A1	5/2004	Okumura	
2004/0099378	A1*	5/2004	Kim et al.	156/345.33
2004/0101667	A1	5/2004	O'Loughlin et al.	
2004/0110354	A1	6/2004	Natzle et al.	
2004/0115876	A1	6/2004	Goundar et al.	
2004/0129224	A1	7/2004	Yamazaki	
2004/0137161	A1	7/2004	Segawa et al.	
2004/0144490	A1	7/2004	Zhao et al.	
2004/0147126	A1	7/2004	Yamashita et al.	
2004/0152342	A1	8/2004	Li	
2004/0154535	A1	8/2004	Chen et al.	
2004/0175929	A1	9/2004	Schmitt et al.	
2004/0182315	A1	9/2004	Laflamme et al.	
2004/0192032	A1	9/2004	Ohmori et al.	
2004/0194799	A1	10/2004	Kim et al.	
2004/0211357	A1	10/2004	Gadgil et al.	
2004/0219789	A1	11/2004	Wood et al.	
2004/0245091	A1	12/2004	Karim et al.	
2005/0001276	A1	1/2005	Gao et al.	
2005/0003676	A1	1/2005	Ho et al.	
2005/0009340	A1	1/2005	Saijo et al.	
2005/0009358	A1	1/2005	Choi et al.	
2005/0026430	A1	2/2005	Kim et al.	
2005/0026431	A1	2/2005	Kazumi et al.	
2005/0035455	A1	2/2005	Hu et al.	
2005/0048801	A1	3/2005	Karim et al.	
2005/0090120	A1	4/2005	Hasegawa et al.	
2005/0098111	A1	5/2005	Shimizu et al.	
2005/0105991	A1	5/2005	Hofmeister et al.	
2005/0112876	A1	5/2005	Wu	
2005/0112901	A1	5/2005	Ji et al.	
2005/0121750	A1	6/2005	Chan et al.	
2005/0164479	A1	7/2005	Perng et al.	
2005/0181588	A1	8/2005	Kim	
2005/0199489	A1	9/2005	Stevens et al.	
2005/0205110	A1	9/2005	Kao et al.	
2005/0205862	A1	9/2005	Koemtzopoulos et al.	
2005/0208215	A1	9/2005	Eguchi et al.	
2005/0218507	A1	10/2005	Kao et al.	
2005/0221552	A1	10/2005	Kao et al.	
2005/0230350	A1	10/2005	Kao et al.	
2005/0236694	A1	10/2005	Wu et al.	
2005/0251990	A1	11/2005	Choi et al.	
2005/0266622	A1	12/2005	Arghavani et al.	
2005/0266691	A1	12/2005	Gu et al.	
2005/0269030	A1	12/2005	Kent et al.	
2005/0287755	A1	12/2005	Bachmann	
2005/0287771	A1	12/2005	Seamons et al.	
2006/0000805	A1	1/2006	Todorow et al.	
2006/0005856	A1	1/2006	Sun et al.	
2006/0006057	A1	1/2006	Laermer	
2006/0016783	A1	1/2006	Wu et al.	
2006/0019456	A1	1/2006	Bu et al.	
2006/0019486	A1	1/2006	Yu et al.	
2006/0021574	A1	2/2006	Armour et al.	
2006/0024954	A1	2/2006	Wu et al.	
2006/0024956	A1	2/2006	Zhijian et al.	
2006/0033678	A1	2/2006	Lubomirsky et al.	
2006/0040055	A1	2/2006	Nguyen et al.	
2006/0043066	A1	3/2006	Kamp	
2006/0046412	A1	3/2006	Nguyen et al.	
2006/0046419	A1	3/2006	Sandhu et al.	
2006/0046484	A1	3/2006	Abatchev et al.	
2006/0051966	A1	3/2006	Or et al.	
2006/0051968	A1	3/2006	Joshi et al.	
2006/0060942	A1	3/2006	Minixhofer et al.	
2006/0093756	A1	5/2006	Rajagopalan et al.	
2006/0097397	A1	5/2006	Russell et al.	
2006/0102076	A1	5/2006	Smith et al.	
2006/0121724	A1	6/2006	Yue et al.	
2006/0124242	A1	6/2006	Kanarik et al.	
2006/0130971	A1	6/2006	Chang et al.	
2006/0157449	A1	7/2006	Takahashi et al.	
2006/0166107	A1	7/2006	Chen et al.	
2006/0166515	A1	7/2006	Karim et al.	
2006/0185592	A1	8/2006	Matsuura	
2006/0191479	A1	8/2006	Mizukami et al.	
2006/0207504	A1	9/2006	Hasebe et al.	
2006/0211260	A1	9/2006	Tran et al.	
2006/0216878	A1	9/2006	Lee	
2006/0216923	A1	9/2006	Tran et al.	
2006/0222481	A1	10/2006	Foree	
2006/0226121	A1	10/2006	Aoi	
2006/0228889	A1	10/2006	Edelberg et al.	
2006/0240661	A1	10/2006	Annapragada et al.	
2006/0244107	A1	11/2006	Sugihara	

(56) **References Cited**

U.S. PATENT DOCUMENTS

2006/0246217 A1 11/2006 Weidman et al.
2006/0251800 A1 11/2006 Weidman et al.
2006/0251801 A1 11/2006 Weidman et al.
2006/0252252 A1 11/2006 Zhu et al.
2006/0260750 A1 11/2006 Rueger
2006/0261490 A1 11/2006 Su et al.
2006/0264003 A1 11/2006 Eun
2006/0264043 A1 11/2006 Stewart et al.
2007/0048977 A1 3/2007 Lee et al.
2007/0071888 A1 3/2007 Shanmugasundram et al.
2007/0072408 A1 3/2007 Enomoto et al.
2007/0090325 A1 4/2007 Hwang et al.
2007/0099428 A1 5/2007 Shamiryan et al.
2007/0099431 A1 5/2007 Li
2007/0099438 A1 5/2007 Ye et al.
2007/0107750 A1 5/2007 Sawin et al.
2007/0108404 A1 5/2007 Stewart et al.
2007/0111519 A1 5/2007 Lubomirsky et al.
2007/0117396 A1 5/2007 Wu et al.
2007/0119370 A1 5/2007 Ma et al.
2007/0119371 A1 5/2007 Ma et al.
2007/0123051 A1 5/2007 Arghavani et al.
2007/0131274 A1 6/2007 Stollwerck et al.
2007/0181057 A1 8/2007 Lam et al.
2007/0197028 A1 8/2007 Byun et al.
2007/0212288 A1 9/2007 Holst
2007/0231109 A1 10/2007 Pak et al.
2007/0232071 A1 10/2007 Balseanu et al.
2007/0235134 A1 10/2007 Iimuro
2007/0238321 A1 10/2007 Futase et al.
2007/0264820 A1 11/2007 Liu
2007/0266946 A1 11/2007 Choi
2007/0269976 A1 11/2007 Futase et al.
2007/0277734 A1 12/2007 Lubomirsky et al.
2007/0281106 A1 12/2007 Lubomirsky et al.
2008/0044990 A1 2/2008 Lee
2008/0063810 A1 3/2008 Park et al.
2008/0081483 A1 4/2008 Wu
2008/0085604 A1 4/2008 Hoshino et al.
2008/0099147 A1 5/2008 Myo et al.
2008/0099431 A1 5/2008 Kumar et al.
2008/0099876 A1 5/2008 Seto
2008/0115726 A1 5/2008 Ingle et al.
2008/0121970 A1 5/2008 Aritome
2008/0124919 A1 5/2008 Huang et al.
2008/0124937 A1 5/2008 Xu et al.
2008/0142483 A1 6/2008 Hua et al.
2008/0156771 A1 7/2008 Jeon et al.
2008/0160210 A1 7/2008 Yang et al.
2008/0162781 A1 7/2008 Haller et al.
2008/0171407 A1 7/2008 Nakabayashi et al.
2008/0173906 A1 7/2008 Zhu
2008/0182381 A1 7/2008 Kiyotoshi
2008/0182382 A1 7/2008 Ingle et al.
2008/0230519 A1 9/2008 Takahashi
2008/0233709 A1 9/2008 Conti et al.
2008/0254635 A1 10/2008 Benzel et al.
2008/0261404 A1 10/2008 Kozuka et al.
2008/0268645 A1 10/2008 Kao et al.
2008/0292798 A1 11/2008 Huh et al.
2008/0293248 A1 11/2008 Park et al.
2009/0001480 A1 1/2009 Cheng
2009/0004849 A1 1/2009 Eun
2009/0017227 A1 1/2009 Fu et al.
2009/0045167 A1 2/2009 Maruyama
2009/0072401 A1 3/2009 Arnold et al.
2009/0081878 A1 3/2009 Dhindsa
2009/0084317 A1 4/2009 Wu et al.
2009/0087979 A1 4/2009 Raghuram
2009/0095621 A1 4/2009 Kao et al.
2009/0104738 A1 4/2009 Ring et al.
2009/0104764 A1 4/2009 Xia et al.
2009/0104782 A1 4/2009 Lu et al.
2009/0111280 A1 4/2009 Kao et al.
2009/0120464 A1 5/2009 Rasheed et al.
2009/0179300 A1 7/2009 Arai
2009/0189246 A1 7/2009 Wu et al.
2009/0194810 A1 8/2009 Kiyotoshi et al.
2009/0197418 A1 8/2009 Sago
2009/0255902 A1 10/2009 Satoh et al.
2009/0258162 A1 10/2009 Furuta et al.
2009/0269934 A1 10/2009 Kao et al.
2009/0275146 A1 11/2009 Takano et al.
2009/0275205 A1 11/2009 Kiehlbauch et al.
2009/0275206 A1 11/2009 Katz et al.
2009/0280650 A1 11/2009 Lubomirsky et al.
2009/0286400 A1 11/2009 Heo et al.
2009/0294898 A1 12/2009 Feustel et al.
2010/0003824 A1 1/2010 Kadkhodayan et al.
2010/0055408 A1 3/2010 Lee et al.
2010/0059889 A1 3/2010 Gosset et al.
2010/0062603 A1 3/2010 Ganguly et al.
2010/0075503 A1 3/2010 Bencher
2010/0093151 A1 4/2010 Arghavani et al.
2010/0098884 A1 4/2010 Balseanu et al.
2010/0099236 A1 4/2010 Kwon et al.
2010/0099263 A1 4/2010 Kao et al.
2010/0105209 A1 4/2010 Winniczek et al.
2010/0130001 A1 5/2010 Noguchi
2010/0144140 A1 6/2010 Chandrashekar et al.
2010/0164422 A1 7/2010 Shu et al.
2010/0173499 A1 7/2010 Tao et al.
2010/0178748 A1 7/2010 Subramanian
2010/0180819 A1* 7/2010 Hatanaka et al. 118/719
2010/0187534 A1 7/2010 Nishi et al.
2010/0187588 A1 7/2010 Kim et al.
2010/0197143 A1 8/2010 Nishimura
2010/0203739 A1 8/2010 Becker et al.
2010/0240205 A1 9/2010 Son
2010/0294199 A1* 11/2010 Tran et al. .... 118/723 R
2010/0330814 A1 12/2010 Yokota et al.
2011/0008950 A1 1/2011 Xu
2011/0034035 A1 2/2011 Liang et al.
2011/0039407 A1 2/2011 Nishizuka
2011/0045676 A1 2/2011 Park
2011/0053380 A1 3/2011 Sapre et al.
2011/0061810 A1 3/2011 Ganguly et al.
2011/0081782 A1 4/2011 Liang et al.
2011/0100489 A1 5/2011 Orito
2011/0111596 A1 5/2011 Kanakasabapathy
2011/0114601 A1 5/2011 Lubomirsky et al.
2011/0115378 A1 5/2011 Lubomirsky et al.
2011/0143542 A1 6/2011 Feurprier et al.
2011/0151674 A1 6/2011 Tang et al.
2011/0151676 A1 6/2011 Ingle et al.
2011/0151677 A1 6/2011 Wang et al.
2011/0151678 A1 6/2011 Ashtiani et al.
2011/0159690 A1 6/2011 Chandrashekar et al.
2011/0165771 A1 7/2011 Ring et al.
2011/0195575 A1 8/2011 Wang
2011/0226734 A1 9/2011 Sumiya et al.
2011/0230052 A1 9/2011 Tang et al.
2011/0232737 A1 9/2011 Ruletzki et al.
2011/0266252 A1 11/2011 Thadani et al.
2011/0266682 A1 11/2011 Edelstein et al.
2011/0294300 A1 12/2011 Zhang et al.
2011/0298061 A1 12/2011 Siddiqui et al.
2012/0003782 A1 1/2012 Byun et al.
2012/0009796 A1 1/2012 Cui et al.
2012/0025289 A1 2/2012 Liang et al.
2012/0031559 A1 2/2012 Dhindsa et al.
2012/0068242 A1 3/2012 Shin et al.
2012/0103518 A1 5/2012 Kakimoto
2012/0129354 A1 5/2012 Luong
2012/0135576 A1 5/2012 Lee et al.
2012/0161405 A1 6/2012 Mohn et al.
2012/0180954 A1 7/2012 Yang et al.
2012/0196447 A1 8/2012 Yang et al.
2012/0211462 A1 8/2012 Zhang et al.
2012/0223048 A1 9/2012 Paranjpe et al.
2012/0225557 A1 9/2012 Serry et al.
2012/0228642 A1 9/2012 Aube et al.
2012/0238102 A1 9/2012 Zhang et al.
2012/0238103 A1 9/2012 Zhang et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2012/0247671	A1	10/2012	Sugawara
2012/0267346	A1	10/2012	Kao et al.
2012/0285621	A1	11/2012	Tan
2012/0292664	A1	11/2012	Kanike
2012/0309204	A1	12/2012	Kang et al.
2013/0005103	A1	1/2013	Liu et al.
2013/0034968	A1	2/2013	Zhang et al.
2013/0045605	A1	2/2013	Wang et al.
2013/0052827	A1	2/2013	Wang et al.
2013/0052833	A1	2/2013	Ranjan et al.
2013/0059440	A1	3/2013	Wang et al.
2013/0082197	A1	4/2013	Yang et al.
2013/0089988	A1	4/2013	Wang et al.
2013/0119483	A1	5/2013	Alptekin et al.
2013/0130507	A1	5/2013	Wang et al.
2013/0224960	A1	8/2013	Payyapilly et al.
2013/0260533	A1	10/2013	Sapre et al.
2013/0260564	A1	10/2013	Sapre et al.
2013/0298942	A1	11/2013	Ren et al.
2014/0004708	A1	1/2014	Thedjoisworo
2014/0021673	A1	1/2014	Chen et al.
2014/0057447	A1	2/2014	Yang et al.
2014/0065842	A1	3/2014	Anthis et al.
2014/0080308	A1	3/2014	Chen et al.
2014/0080309	A1	3/2014	Park
2014/0080310	A1	3/2014	Chen et al.
2014/0083362	A1	3/2014	Lubomirsky et al.
2014/0087488	A1	3/2014	Nam et al.
2014/0097270	A1	4/2014	Liang et al.
2014/0099794	A1	4/2014	Ingle et al.
2014/0141621	A1	5/2014	Ren et al.
2014/0166617	A1	6/2014	Chen
2014/0166618	A1	6/2014	Tadigadapa et al.
2014/0190410	A1	7/2014	Kim
2014/0199851	A1	7/2014	Nemani et al.
2014/0227881	A1	8/2014	Lubomirsky et al.
2014/0234466	A1	8/2014	Gao et al.
2014/0248780	A1	9/2014	Ingle et al.
2014/0256131	A1	9/2014	Wang et al.
2014/0262031	A1	9/2014	Belostotskiy et al.
2014/0262038	A1	9/2014	Wang et al.
2014/0264533	A1	9/2014	Simsek-Ege
2014/0271097	A1	9/2014	Wang et al.
2014/0273406	A1	9/2014	Wang et al.
2014/0273451	A1	9/2014	Wang et al.
2014/0273462	A1	9/2014	Simsek-Ege et al.
2014/0273489	A1	9/2014	Wang et al.
2014/0273491	A1	9/2014	Zhang et al.
2014/0273492	A1	9/2014	Anthis et al.
2014/0273496	A1	9/2014	Kao
2014/0288528	A1	9/2014	Py et al.
2014/0302678	A1	10/2014	Paterson et al.
2014/0302680	A1	10/2014	Singh
2014/0308758	A1	10/2014	Nemani et al.
2014/0308816	A1	10/2014	Wang et al.
2014/0311581	A1	10/2014	Belostotskiy et al.
2014/0342532	A1	11/2014	Zhu
2014/0342569	A1	11/2014	Zhu et al.
2014/0349477	A1	11/2014	Chandrashekar et al.
2015/0011096	A1	1/2015	Chandrasekharan et al.
2015/0014152	A1	1/2015	Hoinkis et al.
2015/0031211	A1	1/2015	Sapre et al.
2015/0060265	A1	3/2015	Cho et al.
2015/0079797	A1	3/2015	Chen et al.
2015/0126035	A1	5/2015	Diao et al.
2015/0126039	A1	5/2015	Korolik et al.
2015/0126040	A1	5/2015	Korolik et al.
2015/0129541	A1	5/2015	Wang et al.
2015/0129545	A1	5/2015	Ingle et al.
2015/0129546	A1	5/2015	Ingle et al.
2015/0132968	A1	5/2015	Ren et al.
2015/0155177	A1	6/2015	Zhang et al.
2015/0170879	A1	6/2015	Nguyen et al.
2015/0170920	A1	6/2015	Purayath et al.
2015/0170935	A1	6/2015	Wang et al.
2015/0170943	A1	6/2015	Nguyen et al.
2015/0171008	A1	6/2015	Luo
2015/0179464	A1	6/2015	Wang et al.
2015/0206764	A1	7/2015	Wang et al.
2015/0214066	A1	7/2015	Luere et al.
2015/0214067	A1	7/2015	Zhang et al.
2015/0214092	A1	7/2015	Purayath et al.
2015/0214337	A1	7/2015	Ko et al.
2015/0221541	A1	8/2015	Nemani et al.
2015/0235863	A1	8/2015	Chen
2015/0235865	A1	8/2015	Wang et al.
2015/0235867	A1	8/2015	Nishizuka
2015/0247231	A1	9/2015	Nguyen et al.
2015/0249018	A1	9/2015	Park et al.
2015/0275361	A1	10/2015	Lubomirsky et al.
2015/0275375	A1	10/2015	Kim et al.

FOREIGN PATENT DOCUMENTS

CN	1412861	A	4/2003
CN	101465386	A	6/2009
EP	0329406		8/1989
EP	0376252	A2	7/1990
EP	0475567		3/1992
EP	0 496 543	A2	7/1992
EP	0697467	A1	2/1996
EP	0913498		5/1999
EP	1099776		5/2001
EP	1107288		6/2001
EP	1496542		1/2005
EP	1568797		8/2005
GB	2285174		6/1995
JP	61-276977	A	12/1986
JP	2058836	A	2/1990
JP	02-121330	A	5/1990
JP	4-239750		7/1992
JP	4-341568	A	11/1992
JP	07-130713	A	5/1995
JP	7-161703	A	6/1995
JP	7297543		11/1995
JP	08-306671	A	11/1996
JP	09153481	A	6/1997
JP	09-205140	A	8/1997
JP	10-178004	A	6/1998
JP	2010-154699		6/1998
JP	11124682		5/1999
JP	H11-204442		7/1999
JP	2000-012514	A	1/2000
JP	2001-308023		11/2001
JP	2002-100578		4/2002
JP	2002-141349		5/2002
JP	2002-222861	A	8/2002
JP	2002-256235		9/2002
JP	2003-019433		1/2003
JP	2003-059914		2/2003
JP	2003-179038	A	6/2003
JP	2003-217898		7/2003
JP	2003-318158	A	11/2003
JP	2003-347278	A	12/2003
JP	2004-047956	A	2/2004
JP	2004-156143	A	6/2004
JP	04-239723	A	8/2004
JP	2005-033023	A	2/2005
JP	2007-173383	A	7/2007
JP	08-148470	A	6/2008
JP	2009-044129	A	2/2009
KR	10-0155601	B1	12/1998
KR	10-0236219	B1	12/1999
KR	1020000008278	A	2/2000
KR	2000-0044928		7/2000
KR	2001-0014064	A	2/2001
KR	10-2001-0049274	A	6/2001
KR	10-2001-0058774	A	7/2001
KR	10-2001-0082109		8/2001
KR	10-2003-0054726	A	7/2003
KR	1020030081177		10/2003
KR	1020030096140		12/2003
KR	10-2004-0049739	A	6/2004
KR	10-2004-0096365	A	11/2004

(56) **References Cited**

FOREIGN PATENT DOCUMENTS

KR	10-2008-0013174	A	2/2008
KR	1020080063988	A	7/2008
KR	10-2009-0080533	A	7/2009
KR	10-2010-0013980	A	2/2010
KR	10-2010-0074508	A	7/2010
KR	10-2010-0075957	A	7/2010
KR	10/2010/0083629	A	7/2010
KR	10-2010-0099535	A	9/2010
KR	10-2011-0086540	A	7/2011
KR	1020110126675	A	11/2011
KR	1020120082640	A	7/2012
WO	92/20833	A1	11/1992
WO	99/26277	A1	5/1999
WO	9954920	A2	10/1999
WO	99/62108	A2	12/1999
WO	00/13225	A1	3/2000
WO	00/22671		4/2000
WO	01/94719	A1	12/2001
WO	02083981	A2	10/2002
WO	03014416		2/2003
WO	2004/006303		1/2004
WO	2004/074932		9/2004
WO	2004/114366	A2	12/2004
WO	2005036615	A2	4/2005
WO	2006/069085	A2	6/2006
WO	2009/071627	A2	6/2009
WO	2011/087580	A1	7/2011
WO	2011/115761	A2	9/2011
WO	2011/139435	A2	11/2011
WO	2012/018449	A2	2/2012
WO	2012/125654	A2	9/2012

OTHER PUBLICATIONS

Cho et al., "Dual Discharge Modes Operation of an Argon Plasma Generated by Commercial Electronic Ballast for Remote Plasma Removal Process," IEEE Transactions on Plasma Science, vol. 42, No. 6, , Jun. 2014, 4 pages.
Cho et al., "Dielectric-barrier microdischarge structure for effic ient positive-column plasma using a thick-film ceramic sheet," IEEE Trans. Plasma Sci., vol. 37, No. 8, Aug. 2009, 4 pgs.
Cho et al., "Three-dimensional spatiotemporal behaviors of light emission from discharge plasma of alternating current plasma display panels," Appl. Phys. Lett. , vol. 92, No. 22, Jun. 2008, 3pgs.
Cho et al., "Analysis of address discharge modes by using a three-dimensional plasma display panel," IEEE Trans. Plasma Sci. , vol. 36, Oct. 2008, 4 pgs.
Derwent 2006-065772, Formation of multilayer enscapulating film over substrate, e.g. displace device, comprising delivering mixture precursors and hydrogen gas into substrate processing system, 2006.
Goebels, F.J. et al. "Arbitrary Polarization from Annular Slot Planar Antennas." Ire Transactions on Antennas and Propagation, Jul. 1961, 8 pgs.
Kim et al., "Pendulum electrons in micro hollow cathode di scharges," IEEE Trans. Plasma Sci. , vol. 36, No. 4, pp. Aug. 2008, 2 pgs.
Redolfi et al., "Bulk FinFET fabrication with new approaches for oxide topography control using dry removal techniques," Solid-State Electron., vol. 71, May 2012, 7 pgs.
Schoenbach et al.,"High-pressure hollow cathode di scharges," Plasma Sources Sci. Te chnol.,vol. 6, No. 4, Nov. 1997, 10 pgs.
International Search Report and Written Opinion of PCT/US2013/076217 mailed on Apr. 28, 2014, 11 pages.
C.C. Tang and D. W. Hess, Tungsten Etching in CF4 and SF6 Discharges, J. Electrochem. Soc., 1984, 131 (1984) p. 115-120.
Yang, R., "Advanced in situ pre-Ni silicide (Siconi) cleaning at 65 nm to resolve defects in NiSix modules," J. Vac. Sci., Technol. B, Microelectron. Nanometer Struct., vol. 28, No. 1, Jan. 2010, 6 pgs.
Yasaka, Y. et al. "Planar microwave discharges with active control of plasma uniformity". Physics of Plasmas, vol. 9 No. 3, Mar. 2002, 7 pgs.
Yasuda et al., "Dual-function remote plasma etching/cleaning system applied to selective etching of Si02 and removal of polymeric residues," J. Vac. Sci. Technol., A, vol. 11, No. 5, 1993, 12 pgs.
C.K. Hu, et al. "Reduced Electromigration of Cu Wires by Surface Coating" Applied Physics Letters, vol. 81, No. 10, Sep. 2, 2002—pp. 1782-1784.
European Search Report dated May 23, 2006 for EP Application No. 05251143.3.
European Examination Report dated Nov. 13, 2007 for EP Application No. 05251143.3.
EP Partial Search Report, Application No. 08150111.601235/1944796, dated Aug. 22, 2008.
Eze, F. C., "Electroless deposition of CoO thin films," J. Phys. D: Appl. Phys. 32 (1999), pp. 533-540.
Galiano et al. "Stress-Temperature Behavior of Oxide Films Used for Intermetal Dielectric Applications", VMIC Conference, Jun. 9-10, 1992, pp. 100-106.
Iijima, et al., "Highly Selective SiO_2 Etch Employing Inductively Coupled Hydro-Fluorocarbon Plasma Chemistry for Self Aligned Contact Etch", Jpn. J. Appl. Phys., Sep. 1997, pp. 5498-5501, vol. 36, Part 1, No. 9A.
International Search Report of PCT/US2009/059743 mailed on Apr. 26, 2010, 4 pages.
International Search Report of PCT/US2012/061726 mailed on May 16, 2013, 3 pages.
International Search Report of PCT/2013/052039 mailed on Nov. 8, 2013, 9 pages.
International Search Report of PCT/2013/037202 mailed on Aug. 23, 2013, 11 pages.
Lin, et al., "Manufacturing of Cu Electroless Nickel/Sn—Pb Flip Chip Solder Bumps", IEEE Transactions on Advanced Packaging, vol. 22, No. 4 (Nov. 1999), pp. 575-579.
Lopatin, et al., "Thin Electroless barrier for copper films", Part of the SPIE Conference of Multilevel Interconnect technology II, SPIE vol. 3508 (1998), pp. 65-77.
Musaka, "Single Step Gap Filling Technology fo Subhalf Micron Metal Spacings on Plasma Enhanced TEOS/O_2 Chemical Vapor Deposition System," Extended Abstracts of the 1993 International Conference on Solid State Devices and Materials pages, 1993, 510-512.
Pearlstein, Fred. "Electroless Plating," J. Res. Natl. Bur. Stan., Ch. 31 (1974), pp. 710-747.
Saito, et al., "Electroless deposition of Ni—B, Co—B and Ni—Co—B alloys using dimethylamineborane as a reducing agent," Journal of Applied Electrochemistry 28 (1998), pp. 559-563.
Schacham-Diamond, et al., "Electrochemically deposited thin film alloys for ULSI and MEMS applications," Microelectronic Engineering 50 (2000), pp. 525-531.
Schacham-Diamond, et al. "Material properties of electroless 100-200 nm thick CoWP films," Electrochemical Society Proceedings, vol. 99-34, pp. 102-110, pub 2000.
Smayling, et al., "APF® Pitch-Halving for 2nm Logic Cells using Gridded Design Rules", proceedings of the SPIE, 2008, 8 pages.
Vassiliev, et al., "Trends in void-free pre-metal CVD dielectrics," Solid State Technology, Mar. 2001, pp. 129-136.
Weston, et al., "Ammonium Compounds," Kirk-Othmer Encyclopedia of Chemical Technology, 2003,30 pages see pp. 717-718, John Wiley & Sons, Inc.
Yosi Shacham-Diamond, et al. "High Aspect Ratio Quarter-Micron Electroless Copper Integrated Technology", Microelectronic Engineering 37/38 (1997) pp. 77-88.
Abraham, "Reactive Facet Tapering of Plasma Oxide for Multilevel Interconnect Applications", IEEE, V-MIC Conference, Jun. 15-16, 1987, pp. 115-121.
Applied Materials, Inc., "Applied Siconi™ Preclean," printed on Aug. 7, 2009, 8 pages.
Carlson, et al., "A Negative Spacer Lithography Process for Sub-100nm Contact Holes and Vias", University of California at Berkeley, Jun. 19, 2007, 4 pp.
Chang et al. "Frequency Effects and Properties of Plasma Deposited Fluorinated Silicon Nitride", J. Vac Sci Technol B 6(2), Mar./Apr. 1988, pp. 524-532.

(56) **References Cited**

OTHER PUBLICATIONS

Cheng, et al., "New Test Structure to Identify Step Coverage Mechanisms in Chemical Vapor Deposition of Silicon Dioxide," Appl. Phys. Lett., 58 (19), May 13, 1991, p. 2147-2149.
Examination Report dated Jun. 28, 2010 for European Patent Application No. 05251143.3. I.
Fukada et al., "Preparation of SiOF Films with Low Dielectric Constant by ECR Plasma CVD," ISMIC, DUMIC Conference, Feb. 21-22, 1995, pp. 43-49.
Hashim et al., "Characterization of thin oxide removal by RTA Treatment," ICSE 1998 Proc. Nov. 1998, Rangi, Malaysia, pp. 213-216.
Hausmann, et al., "Rapid Vapor Deposition of Highly Conformal Silica Nanolaminates," Science, Oct. 11, 2002, p. 402-406, vol. 298.
Hayasaka, N. et al. "High Quality Low Dielectric Constant SiO2 CVD Using High Density Plasma," Proceedings of the Dry Process Symposium, 1993, pp. 163-168.
Hwang et al., "Smallest Bit-Line Contact of 76nm pitch on NAND Flash Cell by using Reversal PR (Photo Resist) and SADP (Self-Align Double Patterning) Process," IEEE/SEMI Advanced Semiconductor Manufacturing Conference, 2007, 3 pages.
International Search Report and Written Opinion of the International Searching Authority mailed Jul. 3, 2008 (PCT/US05/46226).
International Search Report and Written Opinion for PCT Application No. PCT/US2011/027221, mailed on Nov. 1, 2011, 8 pages.
International Search Report and Written Opinion of PCT/US2010/057676 mailed on Jun. 27, 2011, 9 pages.
International Search Report and Written Opinion of PCT/US2011/030582 mailed Dec. 7, 2011, 9 pages.
International Search Report and Written Opinion of PCT/US2011/064724 mailed on Oct. 12, 2012, 8 pages.
International Search Report and Written Opinion of PCT/US2012/028952 mailed on Oct. 29, 2012, 9 pages.
International Search Report and Written Opinion of PCT/US2012/048842 mailed on Nov. 28, 2012, 10 pages.
International Search Report and Written Opinion of PCT/US2012/053329 mailed on Feb. 15, 2013, 8 pages.
International Search Report and Written Opinion of PCT/US2012/057294 mailed on Mar. 18, 2013, 12 pages.
International Search Report and Written Opinion of PCT/US2012/057358 mailed on Mar. 25, 2013, 10 pages.
International Search Report and Written Opinion of PCT/US2012/058818 mailed on Apr. 1, 2013, 9 pages.
International Search Report and Written Opinion of the International Searching Authority for PCT Application No. PCT/US2012/028957, mailed on Oct. 18, 2012, 9 pages.
Japanese Patent Office, Official Action for Application No. 2007-317207 mailed on Dec. 21, 2011, 2 pages.
Jung, et al., "Patterning with amorphous carbon spacer for expanding the resolution limit of current lithography tool", Proc. SPIE , 2007, 9 pages, vol. 6520, 65201C.
Laxman, "Low ϵ Dielectrics: CVD Fluorinated Silicon Dioxides", Semiconductor International, May 1995, pp. 71-74.
Lee, et al., "Dielectric Planarization Techniques for Narrow Pitch Multilevel Interconnects," IEEE, V-MIC Conference Jun. 15-16, 1987, pp. 85-92 (1987).
Matsuda, et al. "Dual Frequency Plasma CVD Fluorosilicate Glass Deposition for 0.25 um Interlevel Dielectrics", ISMIC, DUMIC Conference Feb. 21-22, 1995, 1995. pp. 22-28.
Meeks, Ellen et al., "Modeling of SiO_2 deposition in high density plasma reactors and comparisons of model predictions with experimental measurements," J. Vac. Sci. Technol. A, Mar./Apr. 1998, pp. 544-563, vol. 16(2).
Mukai, et al., "A Study of CD Budget in Spacer Patterning Process", Toshiba, SPIE 2008, Feb. 26, 2008, 12 pages.
Nishino, et al.; Damage-Free Selective Etching of SI Native Oxides Using NH3/NF3 and SF6/H20 Down-Flow Etching, The Japanese Society of Applied Physics, vol. 74, No. 2, pp. 1345-1348, XP-002491959, Jul. 15, 1993.
Ogawa, et al., "Dry Cleaning Technology for Removal of Silicon Native Oxide Employing Hot NH3/NF3 Exposure", Japanese Journal of Applied Physics, pp. 5349-5358, Aug. 2002, vol. 41 Part 1, No. 8.
Ota, et al., "Stress Controlled Shallow Trench Isolation Technology to Suppress the Novel Anti-Isotropic Impurity Diffusion for 45nm-Node High Performance CMOSFETs," Symposium on VLSI Technology Digest of Technical Papers, 2005, pp. 138-139.
Qian, et al., "High Density Plasma Deposition and Deep Submicron Gap Fill with Low Dielectric Constant SiOF Films," ISMIC, DUMIC Conference Feb. 21-22, 1995, 1995, pp. 50-56.
Robles, et al. "Effects of RF Frequency and Deposition Rates on the Moisture Resistance of PECVD TEOS-Based Oxide Films", ECS Extended Abstracts, Abstract No. 129, May 1992, pp. 215-216, vol. 92-1.
Shapiro, et al. "Dual Frequency Plasma CVD Fluorosilicate Glass: Water Absorption and Stability", ISMIC, DUMIC Conference Feb. 21-22, 1995, 1995. pp. 118-123.
S.M. Sze, VLSI Technology, McGraw-Hill Book Company, pp. 107, 108, pub 1988.
Usami, et al., "Low Dielectric Constant Interlayer Using Fluorine-Doped Silicon Oxide", Jpn. J. Appl. Phys., Jan. 19, 1994. pp. 408-412, vol. 33 Part 1, No. 1B.
Wang et al.; Ultra High-selectivity silicon nitride etch process using an inductively coupled plasma source; J. Vac. Sci. Techno!. A 16(3),May/Jun. 1998, pp. 1582-1587.
Wolf et al.; Silicon Processing for the VLSI Era; vol. 1; 1986; Lattice Press, pp. 546, 547, 618, 619.
Yu, et al., "Step Coverage Study of Peteos Deposition for Intermetal Dielectric Applications," abstract, VMIC conference, Jun. 12-13, 1990, 7 pages, No. 82.
Yutaka, et al., "Selective Etching of Silicon Native Oxide with Remote-Plasma-Excited Anhydrous Hydrogen Fluoride," Japanese Journal of Applied Physics, 1998, vol. 37, pp. L536-L538.

* cited by examiner

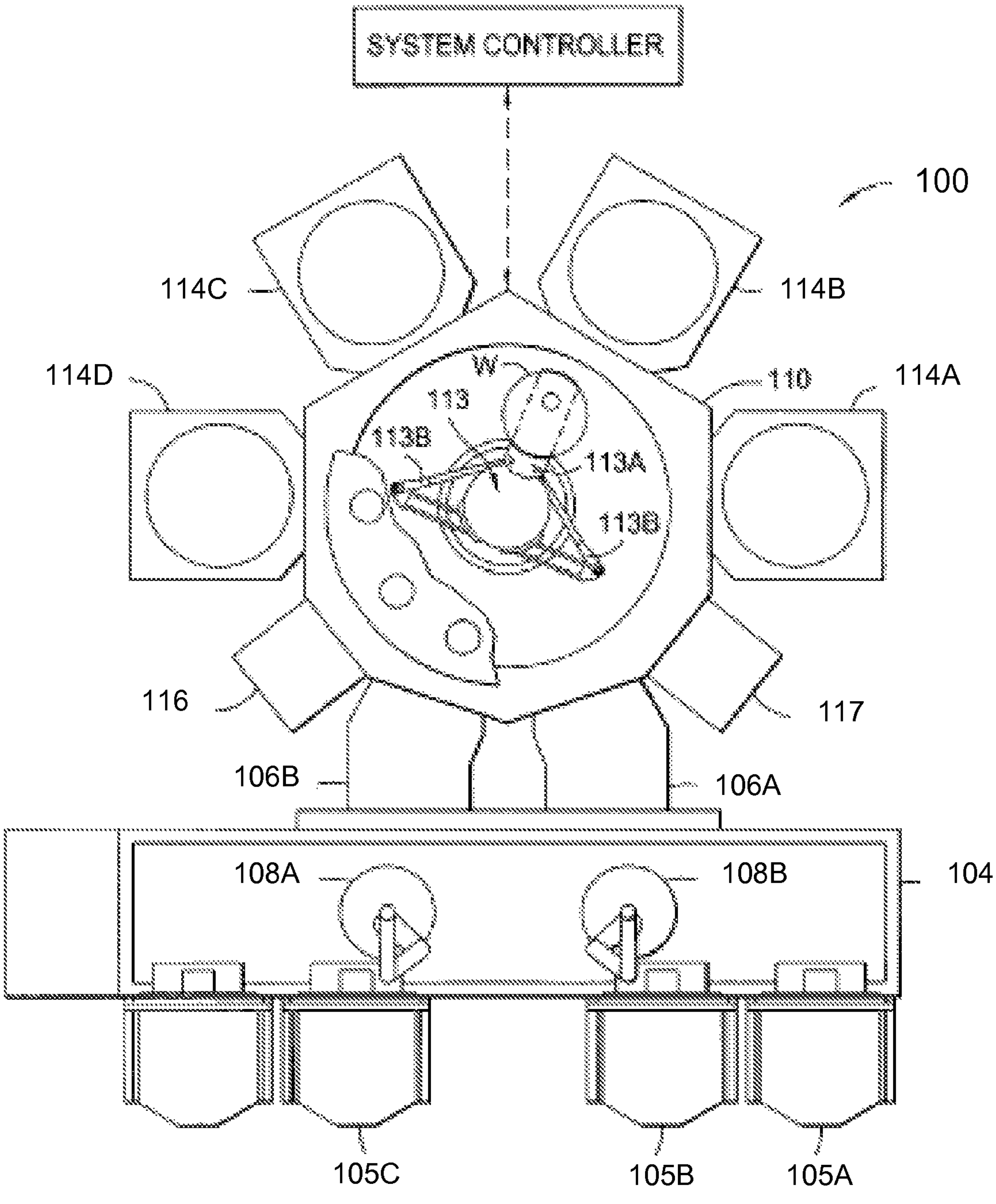

SYSTEM CONTROLLER
100
114C
114B
114D
114A
110
W
113
113B
113A
113B
116
117
106B
106A
108A
108B
104
105C
105B
105A

FIG. 1

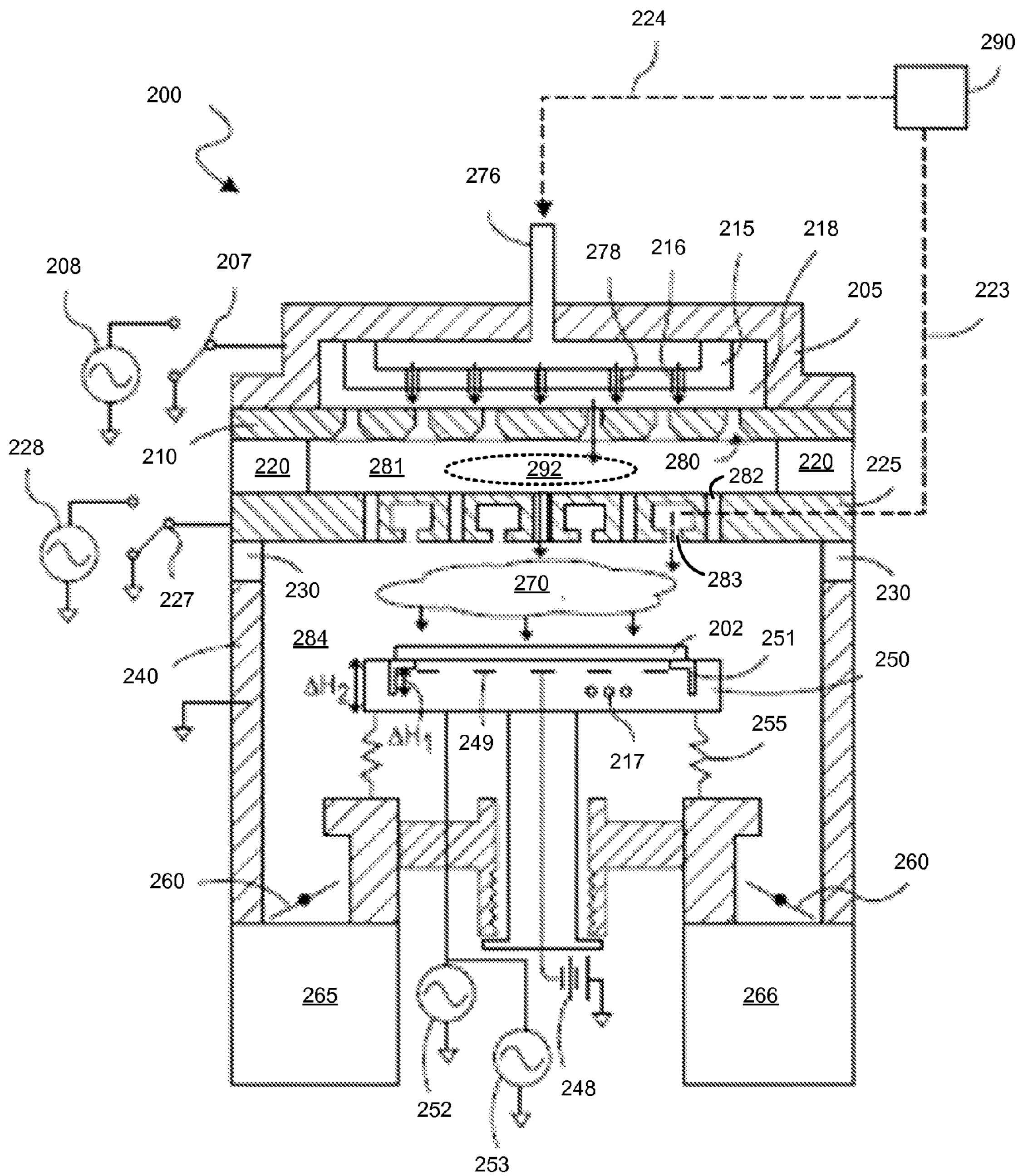

224
290
200
276
223
278
216
215
218
208
207
205
210
220
281
292
280
220
225
228
282
227
230
270
283
230
284
202
251
240
250
ΔH2
ΔH1
249
217
255
260
260
265
266
252
248
253

FIG. 2

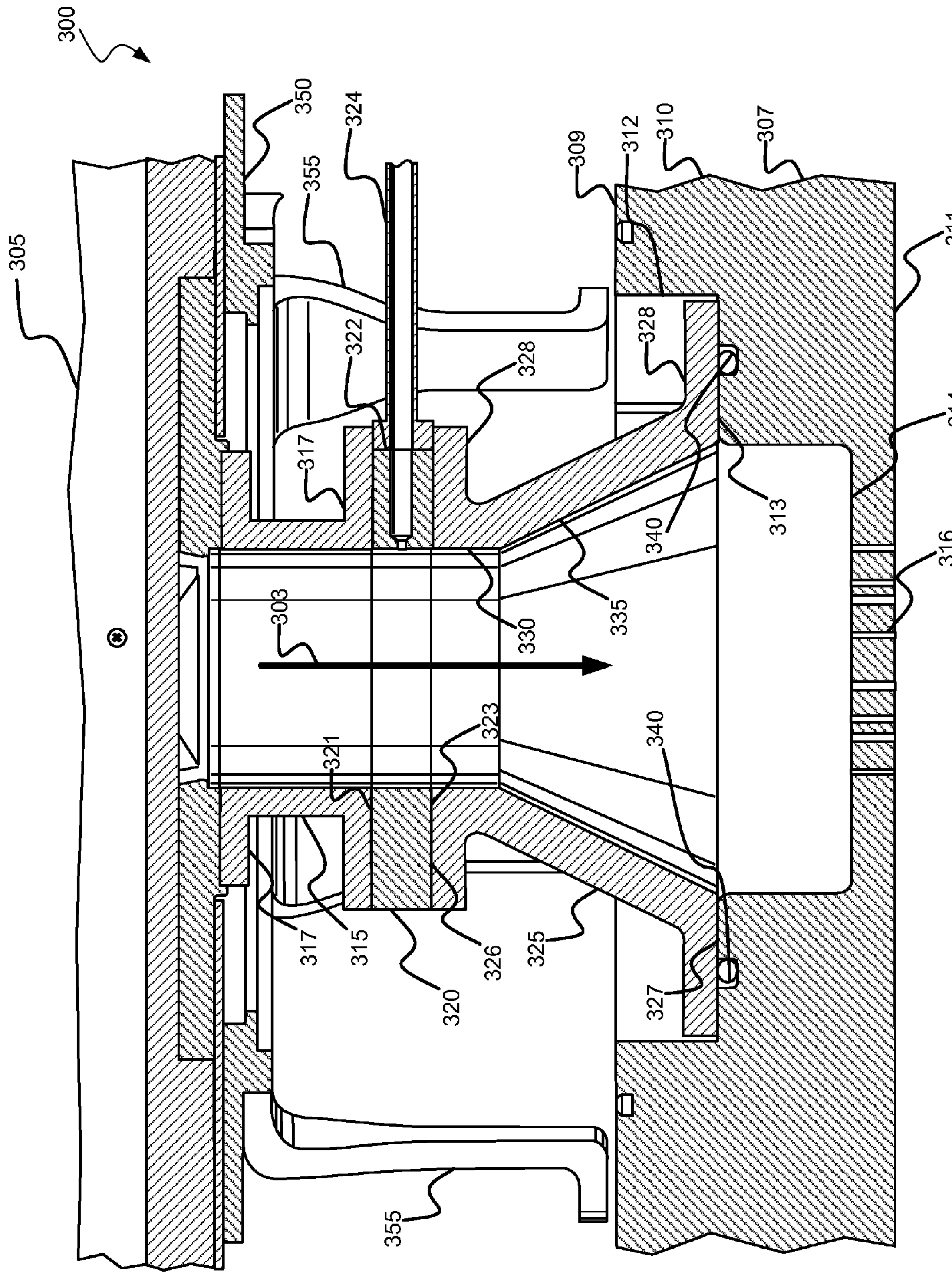

300
305
350
324
355
309
312
310
307
311
322
328
328
317
314
313
340
316
335
330
303
323
340
321
317
315
320
326
325
327
355

FIG. 3

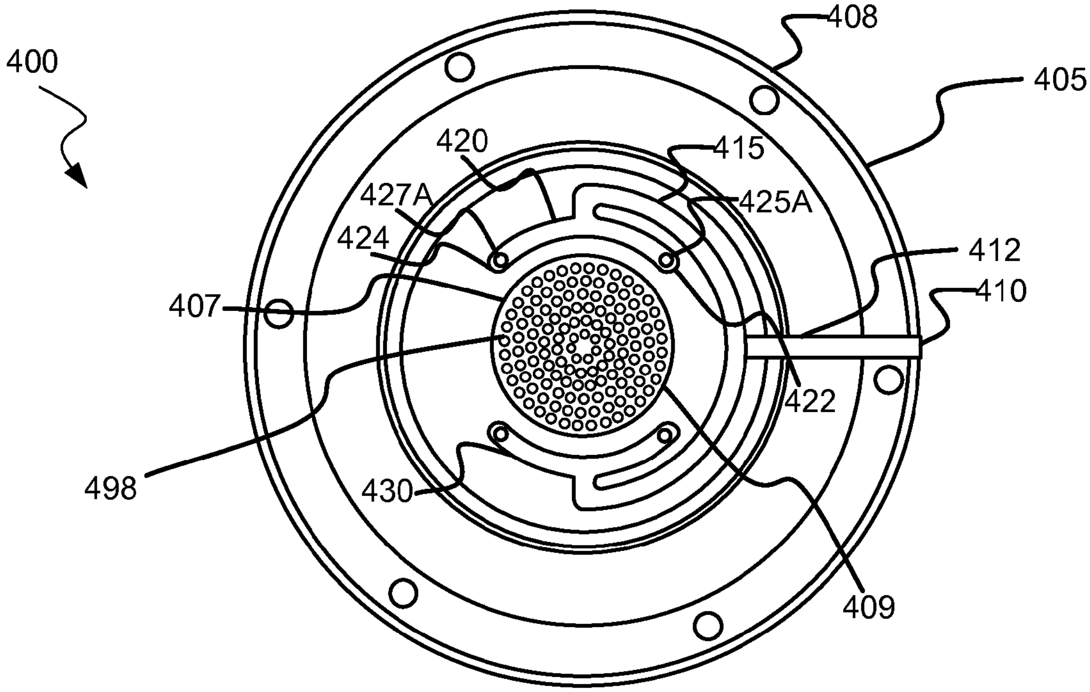

400
408
405
420
415
427A
425A
424
412
407
410
422
498
430
409

FIG. 4A

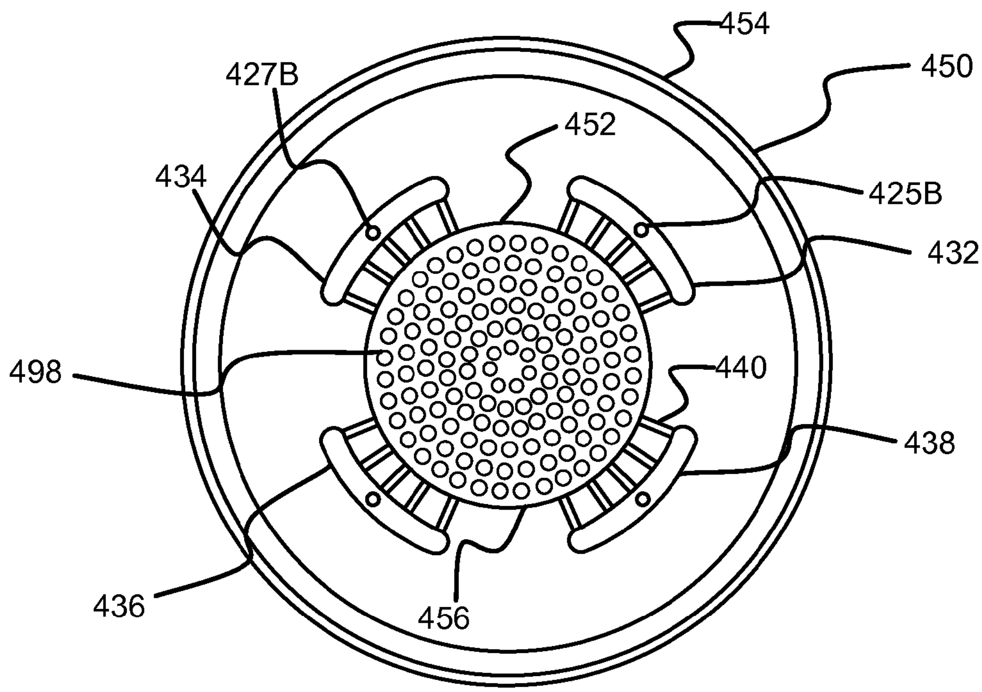

454
450
427B
452
434
425B
432
498
440
438
436
456

FIG. 4B

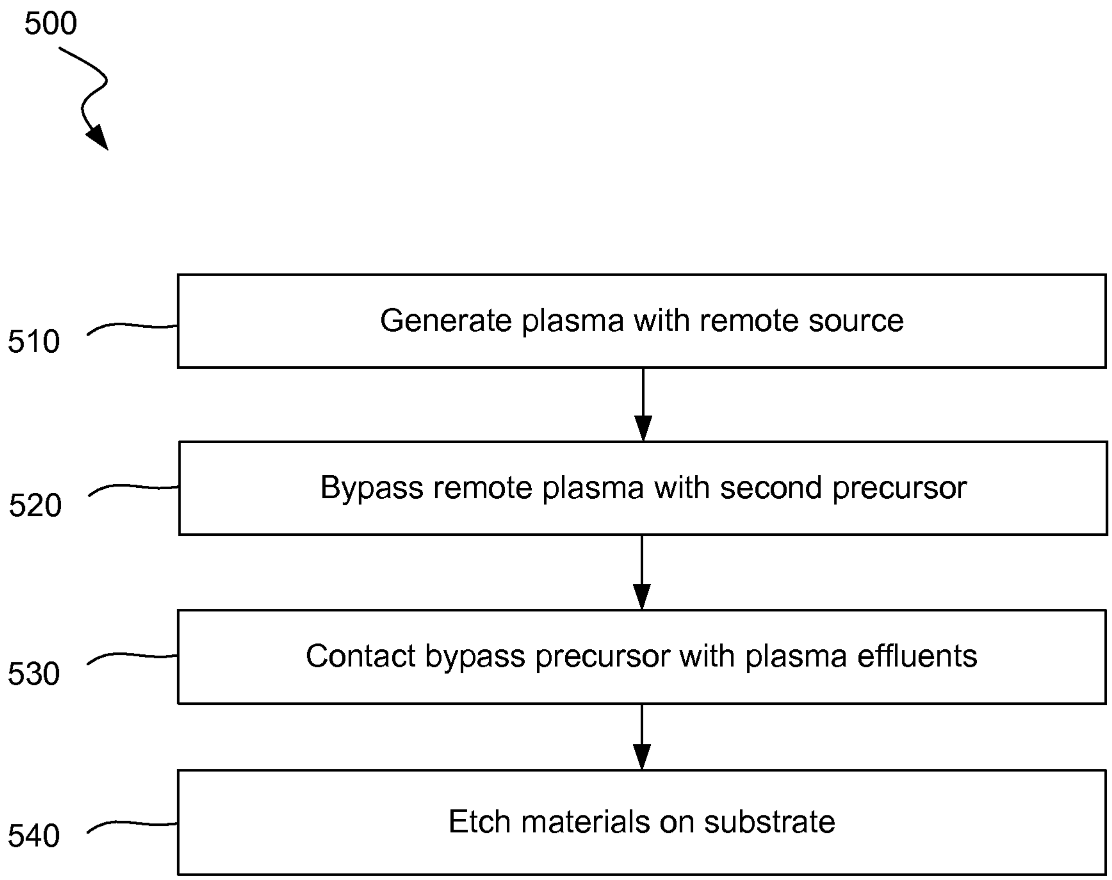

500
510
Generate plasma with remote source
520
Bypass remote plasma with second precursor
530
Contact bypass precursor with plasma effluents
540
Etch materials on substrate

FIG. 5

SEMICONDUCTOR SYSTEM ASSEMBLIES AND METHODS OF OPERATION

CROSS-REFERENCES TO RELATED APPLICATIONS

This Application is related to U.S. application Ser. No. 14/108,683 entitled "SEMICONDUCTOR SYSTEM ASSEMBLIES AND METHODS OF OPERATION," and U.S. application Ser. No. 14/108,719 entitled "SEMICONDUCTOR SYSTEM ASSEMBLIES AND METHODS OF OPERATION," all of which are being filed concurrently on Dec. 17, 2013, the entire disclosures of which are hereby incorporated by reference for all purposes.

TECHNICAL FIELD

The present technology relates to semiconductor systems, processes, and equipment. More specifically, the present technology relates to systems and methods for reducing film contamination and equipment degradation.

BACKGROUND

Integrated circuits are made possible by processes which produce intricately patterned material layers on substrate surfaces. Producing patterned material on a substrate requires controlled methods for removal of exposed material. Chemical etching is used for a variety of purposes including transferring a pattern in photoresist into underlying layers, thinning layers, or thinning lateral dimensions of features already present on the surface. Often it is desirable to have an etch process that etches one material faster than another facilitating, for example, a pattern transfer process. Such an etch process is said to be selective to the first material. As a result of the diversity of materials, circuits, and processes, etch processes have been developed with a selectivity towards a variety of materials.

Etch processes may be termed wet or dry based on the materials used in the process. A wet HF etch preferentially removes silicon oxide over other dielectrics and materials. However, wet processes may have difficulty penetrating some constrained trenches and also may sometimes deform the remaining material. Dry etches produced in local plasmas formed within the substrate processing region can penetrate more constrained trenches and exhibit less deformation of delicate remaining structures. However, local plasmas may damage the substrate through the production of electric arcs as they discharge.

Thus, there is a need for improved systems and methods that can be used to produce high quality devices and structures. These and other needs are addressed by the present technology.

SUMMARY

Systems, chambers, and processes are provided for controlling chamber degradation due to high voltage plasma. The systems may provide configurations for components that allow improved precursor distribution. The chambers may include modified components less likely to degrade due to exposure to plasma. The methods may provide for the limiting or prevention of chamber or component degradation as a result of etching processes performed by system tools.

Exemplary semiconductor processing systems may include a remote plasma source coupled with a processing chamber having a top plate. An inlet assembly may be used to couple the remote plasma source with the top plate and may include a mounting assembly, which in embodiments may include at least two components. The inlet assembly may further include a precursor distribution assembly defining a plurality of distribution channels fluidly coupled with an injection port.

A first component of the mounting assembly may include an annular gas block, and a second component of the mounting assembly may include a mounting block defining a channel and comprising a first mounting surface and a second mounting surface opposite the first mounting surface. In disclosed embodiments, a first section of the channel extending from the first mounting surface may be characterized by a first diameter. A second section of the channel extending from the first section of the channel to the second mounting surface may be characterized by an increasing diameter from the first section of the channel to the second mounting surface. In embodiments, the gas block may be coupled with a first surface of the precursor distribution assembly, and the mounting block may be coupled with a second surface of the precursor distribution assembly opposite the first surface of the precursor distribution assembly.

In embodiments, the precursor distribution assembly may comprise an annular shape. The precursor distribution assembly may include at least two coupled plates, which at least partially define the plurality of distribution channels. A first plate of the at least two coupled plates may at least partially define a first distribution channel extending tangentially from a single injection port to at least two secondary distribution channels. The at least two secondary distribution channels may extend tangentially from the first distribution channel to at least two tertiary distribution apertures. A second plate of the at least two coupled plates may at least partially define a portion of the at least two tertiary distribution apertures. The second plate may further define at least two tertiary distribution channels extending from the at least two tertiary distribution apertures. The second plate may further define at least two quaternary distribution channels extending from the at least two tertiary distribution channels.

Exemplary semiconductor processing systems according to the present technology may include a remote plasma source, and a processing chamber having a top plate. The systems may also include an inlet assembly coupling the remote plasma source with the top plate. The inlet assembly may include a precursor distribution assembly defining the plurality of distribution channels fluidly coupled with a single injection port. The precursor distribution assembly may also include at least two annular plates coupled with each other and at least partially defining a central distribution channel. A first plate of the at least two annular plates may define a single injection port and a first distribution channel tangentially extending from the single injection port. The second plate of the at least two annular plates may define at least two secondary distribution channels in fluid communication with the first distribution channel and the central distribution channel. The inlet assembly may further include a mounting assembly, and the mounting assembly may include at least two components spatially separated by the precursor distribution assembly. The semiconductor processing systems may also include a support assembly coupled with the remote plasma source and including at least one support extension extending from the support assembly towards the top plate. The support extension may be separated from the top plate in a first operational position, and the support extension may be configured to contact the top plate in a second operational position engageable during a processing operation.

Etching methods may be performed utilizing any of the disclosed technology, and the methods may include generating a plasma with a remote plasma source to create plasma effluents of a first precursor. The methods may also include bypassing the remote plasma source with a second precursor flowed into a gas distribution assembly. The gas distribution assembly may be fluidly coupled with the remote plasma source, such as with a central distribution channel. The methods may include contacting the second precursor with the plasma effluents of the first precursor to produce an etching formula. The contacting of the precursors may occur externally to a processing chamber. The methods may also include etching materials on a substrate housed in the processing chamber with the etching formula.

Such technology may provide numerous benefits over conventional systems and techniques. For example, degradation of chamber components may be prevented or limited due to external plasma generation. An additional advantage is that improved etching profiles may be provided based on improved precursor delivery. These and other embodiments, along with many of their advantages and features, are described in more detail in conjunction with the below description and attached figures.

BRIEF DESCRIPTION OF THE DRAWINGS

A further understanding of the nature and advantages of the disclosed technology may be realized by reference to the remaining portions of the specification and the drawings.

FIG. **1** shows a top plan view of an exemplary processing system according to the present technology.

FIG. **2** shows a schematic cross-sectional view of an exemplary processing chamber according to the present technology.

FIG. **3** shows a schematic cross-sectional view of a portion of an exemplary processing chamber according to the disclosed technology.

FIGS. **4**A-B show schematic cross-sectional views of a portion of an exemplary distribution assembly according to the disclosed technology.

FIG. **5** shows a method of etching that may reduce film contamination according to the present technology.

Several of the Figures are included as schematics. It is to be understood that the Figures are for illustrative purposes, and are not to be considered of scale unless specifically stated to be as such.

In the appended figures, similar components and/or features may have the same reference label. Further, various components of the same type may be distinguished by following the reference label by a letter that distinguishes among the similar components. If only the first reference label is used in the specification, the description is applicable to any one of the similar components having the same first reference label irrespective of the letter.

DETAILED DESCRIPTION

The present technology includes systems and components for semiconductor processing. When plasmas are formed in situ in processing chambers, such as with a capacitively coupled plasma ("CCP") for example, exposed surfaces of the chamber may be sputtered or degraded by the plasma or the species produced by the plasma. This may in part be caused by bombardment to the surfaces or surface coatings by generated plasma particles. The extent of the bombardment may itself be related to the voltage utilized in generating the plasma. For example, higher voltage may cause higher bombardment, and further degradation.

Conventional technologies have often dealt with this degradation by providing replaceable components within the chamber. Accordingly, when coatings or components themselves are degraded, the component may be removed and replaced with a new component that will in turn degrade over time. However, the present systems may at least partially overcome or reduce this need to replace components by utilizing external plasma generation. Remote plasma sources may provide multiple benefits over internal plasma sources. For example, the remote plasma chamber core may be coated or composed of material specifically selected based on the plasma being produced. In this way, the remote plasma unit or components of the remote plasma unit such as the electrode may be protected to reduce wear and increase system life. Some conventional technologies utilizing remote plasma systems have reduced operational performance due to recombination of the plasma effluents based on longer flow paths. The present technology, however, may additionally overcome such issues by utilizing an inlet distribution system that reduces the length of travel for plasma species, as well as by allowing the generated plasma effluents to interact with other precursors nearer to the plasma source. Accordingly, the systems described herein provide improved performance and cost benefits over many conventional designs. These and other benefits will be described in detail below.

Although the remaining disclosure will routinely identify specific etching processes utilizing the disclosed technology, it will be readily understood that the systems and methods are equally applicable to deposition and cleaning processes as may occur in the described chambers. Accordingly, the technology should not be considered to be so limited as for use with etching processes alone.

FIG. **1** shows a top plan view of one embodiment of a processing system **100** of deposition, etching, baking, and curing chambers according to embodiments. The processing tool **100** depicted in FIG. **1** may contain a plurality of process chambers, **114**A-D, a transfer chamber **110**, a service chamber **116**, an integrated metrology chamber **117**, and a pair of load lock chambers **106**A-B. The process chambers may include structures or components similar to those described in relation to FIG. **2**, as well as additional processing chambers.

To transport substrates among the chambers, the transfer chamber **110** may contain a robotic transport mechanism **113**. The transport mechanism **113** may have a pair of substrate transport blades **113**A attached to the distal ends of extendible arms **113**B, respectively. The blades **113**A may be used for carrying individual substrates to and from the process chambers. In operation, one of the substrate transport blades such as blade **113**A of the transport mechanism **113** may retrieve a substrate W from one of the load lock chambers such as chambers **106**A-B and carry substrate W to a first stage of processing, for example, an etching process as described below in chambers **114**A-D. If the chamber is occupied, the robot may wait until the processing is complete and then remove the processed substrate from the chamber with one blade **113**A and may insert a new substrate with a second blade (not shown). Once the substrate is processed, it may then be moved to a second stage of processing. For each move, the transport mechanism **113** generally may have one blade carrying a substrate and one blade empty to execute a substrate exchange. The transport mechanism **113** may wait at each chamber until an exchange can be accomplished.

Once processing is complete within the process chambers, the transport mechanism **113** may move the substrate W from the last process chamber and transport the substrate W to a cassette within the load lock chambers **106**A-B. From the load lock chambers **106**A-B, the substrate may move into a factory interface **104**. The factory interface **104** generally may operate to transfer substrates between pod loaders **105**A-D in an atmospheric pressure clean environment and the load lock chambers **106**A-B. The clean environment in factory interface **104** may be generally provided through air filtration processes, such as HEPA filtration, for example. Factory interface **104** may also include a substrate orienter/aligner (not shown) that may be used to properly align the substrates prior to processing. At least one substrate robot, such as robots **108**A-B, may be positioned in factory interface **104** to transport substrates between various positions/locations within factory interface **104** and to other locations in communication therewith. Robots **108**A-B may be configured to travel along a track system within enclosure **104** from a first end to a second end of the factory interface **104**.

The processing system **100** may further include an integrated metrology chamber **117** to provide control signals, which may provide adaptive control over any of the processes being performed in the processing chambers. The integrated metrology chamber **117** may include any of a variety of metrological devices to measure various film properties, such as thickness, roughness, composition, and the metrology devices may further be capable of characterizing grating parameters such as critical dimensions, sidewall angle, and feature height under vacuum in an automated manner.

Turning now to FIG. **2** is shown a cross-sectional view of an exemplary process chamber system **200** according to the present technology. Chamber **200** may be used, for example, in one or more of the processing chamber sections **114** of the system **100** previously discussed Generally, the etch chamber **200** may include a first capacitively-coupled plasma source to implement an ion milling operation and a second capacitively-coupled plasma source to implement an etching operation and to implement an optional deposition operation. The chamber **200** may include grounded chamber walls **240** surrounding a chuck **250**. In embodiments, the chuck **250** may be an electrostatic chuck that clamps the substrate **202** to a top surface of the chuck **250** during processing, though other clamping mechanisms as would be known may also be utilized. The chuck **250** may include an embedded heat exchanger coil **217**. In the exemplary embodiment, the heat exchanger coil **217** includes one or more heat transfer fluid channels through which heat transfer fluid, such as an ethylene glycol/water mix, may be passed to control the temperature of the chuck **250** and ultimately the temperature of the substrate **202**.

The chuck **250** may include a mesh **249** coupled to a high voltage DC supply **248** so that the mesh **249** may carry a DC bias potential to implement the electrostatic clamping of the substrate **202**. The chuck **250** may be coupled with a first RF power source and in one such embodiment, the mesh **249** may be coupled with the first RF power source so that both the DC voltage offset and the RF voltage potentials are coupled across a thin dielectric layer on the top surface of the chuck **250**. In the illustrative embodiment, the first RF power source may include a first and second RF generator **252**, **253**. The RF generators **252**, **253** may operate at any industrially utilized frequency, however in the exemplary embodiment the RF generator **252** may operate at 60 MHz to provide advantageous directionality. Where a second RF generator **253** is also provided, the exemplary frequency may be 2 MHz.

With the chuck **250** to be RF powered, an RF return path may be provided by a first showerhead **225**. The first showerhead **225** may be disposed above the chuck to distribute a first feed gas into a first chamber region **284** defined by the first showerhead **225** and the chamber wall **240**. As such, the chuck **250** and the first showerhead **225** form a first RF coupled electrode pair to capacitively energize a first plasma **270** of a first feed gas within a first chamber region **284**. A DC plasma bias, or RF bias, resulting from capacitive coupling of the RF powered chuck may generate an ion flux from the first plasma **270** to the substrate **202**, e.g., Ar ions where the first feed gas is Ar, to provide an ion milling plasma. The first showerhead **225** may be grounded or alternately coupled with an RF source **228** having one or more generators operable at a frequency other than that of the chuck **250**, e.g., 13.56 MHz or 60 MHz. In the illustrated embodiment the first showerhead **225** may be selectably coupled to ground or the RF source **228** through the relay **227** which may be automatically controlled during the etch process, for example by a controller (not shown). In disclosed embodiments, chamber **200** may not include showerhead **225** or dielectric spacer **220**, and may instead include only baffle **215** and showerhead **210** described further below.

As further illustrated in the figure, the etch chamber **200** may include a pump stack capable of high throughput at low process pressures. In embodiments, at least one turbo molecular pump **265**, **266** may be coupled with the first chamber region **284** through one or more gate valves **260** and disposed below the chuck **250**, opposite the first showerhead **225**. The turbo molecular pumps **265**, **266** may be any commercially available pumps having suitable throughput and more particularly may be sized appropriately to maintain process pressures below or about 10 mTorr or below or about 5 mTorr at the desired flow rate of the first feed gas, e.g., 50 to 500 sccm of Ar where argon is the first feedgas. In the embodiment illustrated, the chuck **250** may form part of a pedestal which is centered between the two turbo pumps **265** and **266**, however in alternate configurations chuck **250** may be on a pedestal cantilevered from the chamber wall **240** with a single turbo molecular pump having a center aligned with a center of the chuck **250**.

Disposed above the first showerhead **225** may be a second showerhead **210**. In one embodiment, during processing, the first feed gas source, for example, Argon delivered from gas distribution system **290** may be coupled with a gas inlet **276**, and the first feed gas flowed through a plurality of apertures **280** extending through second showerhead **210**, into the second chamber region **281**, and through a plurality of apertures **282** extending through the first showerhead **225** into the first chamber region **284**. An additional flow distributor or baffle **215** having apertures **278** may further distribute a first feed gas flow **216** across the diameter of the etch chamber **200** through a distribution region **218**. In an alternate embodiment, the first feed gas may be flowed directly into the first chamber region **284** via apertures **283** which are isolated from the second chamber region **281** as denoted by dashed line **223**.

Chamber **200** may additionally be reconfigured from the state illustrated to perform an etching operation. A secondary electrode **205** may be disposed above the first showerhead **225** with a second chamber region **281** there between. The secondary electrode **205** may further form a lid or top plate of the etch chamber **200**. The secondary electrode **205** and the first showerhead **225** may be electrically isolated by a dielectric ring **220** and form a second RF coupled electrode pair to capacitively discharge a second plasma **292** of a second feed gas within the second chamber region **281**. Advantageously, the second plasma **292** may not provide a significant RF bias potential on the chuck **250**. At least one electrode of the second RF coupled electrode pair may be coupled with an RF source for energizing an etching plasma. The secondary electrode **205** may be electrically coupled with the second showerhead **210**. In an exemplary embodiment, the first showerhead **225** may be coupled with a ground plane or floating and may be coupled to ground through a relay **227** allowing the first showerhead **225** to also be powered by the RF power source **228** during the ion milling mode of operation. Where the first showerhead **225** is grounded, an RF power source **208**, having one or more RF generators operating at 13.56 MHz or 60 MHz, for example, may be coupled with the secondary electrode **205** through a relay **207** which may allow the secondary electrode **205** to also be grounded during other operational modes, such as during an ion milling operation, although the secondary electrode **205** may also be left floating if the first showerhead **225** is powered.

A second feed gas source, such as nitrogen trifluoride, and a hydrogen source, such as ammonia, may be delivered from gas distribution system **290**, and coupled with the gas inlet **276** such as via dashed line **224**. In this mode, the second feed gas may flow through the second showerhead **210** and may be energized in the second chamber region **281**. Reactive species may then pass into the first chamber region **284** to react with the substrate **202**. As further illustrated, for embodiments where the first showerhead **225** is a multi-channel showerhead, one or more feed gases may be provided to react with the reactive species generated by the second plasma **292**. In one such embodiment, a water source may be coupled with the plurality of apertures **283**.

In an embodiment, the chuck **250** may be movable along the distance H2 in a direction normal to the first showerhead **225**. The chuck **250** may be on an actuated mechanism surrounded by a bellows **255**, or the like, to allow the chuck **250** to move closer to or farther from the first showerhead **225** as a means of controlling heat transfer between the chuck **250** and the first showerhead **225**, which may be at an elevated temperature of 80° C.-150° C., or more. As such, an etch process may be implemented by moving the chuck **250** between first and second predetermined positions relative to the first showerhead **225**. Alternatively, the chuck **250** may include a lifter **251** to elevate the substrate **202** off a top surface of the chuck **250** by distance H1 to control heating by the first showerhead **225** during the etch process. In other embodiments, where the etch process is performed at a fixed temperature such as about 90-110° C. for example, chuck displacement mechanisms may be avoided. A system controller (not shown) may alternately energize the first and second plasmas **270** and **292** during the etching process by alternately powering the first and second RF coupled electrode pairs automatically.

The chamber **200** may also be reconfigured to perform a deposition operation. A plasma **292** may be generated in the second chamber region **281** by an RF discharge which may be implemented in any of the manners described for the second plasma **292**. Where the first showerhead **225** is powered to generate the plasma **292** during a deposition, the first showerhead **225** may be isolated from a grounded chamber wall **240** by a dielectric spacer **230** so as to be electrically floating relative to the chamber wall. In the exemplary embodiment, an oxidizer feed gas source, such as molecular oxygen, may be delivered from gas distribution system **290**, and coupled with the gas inlet **276**. In embodiments where the first showerhead **225** is a multi-channel showerhead, any silicon-containing precursor, such as OMCTS for example, may be delivered from gas distribution system **290**, and directed into the first chamber region **284** to react with reactive species passing through the first showerhead **225** from the plasma **292**. Alternatively the silicon-containing precursor may also be flowed through the gas inlet **276** along with the oxidizer.

FIG. **3** shows a schematic cross-sectional view of a portion of an exemplary processing system **300** according to the disclosed technology. As illustrated, system **300** includes a more detailed view of an exemplary version of a top portion and related components of, for example, system **200** as previously described. System **300** includes a variety of components that may be utilized to deliver precursors to a processing chamber **307** through top plate **310**, which may be similar in aspects to top plate or cover **205** as previously described. Semiconductor processing system **300** may include remote plasma source **305** that may be configured to produce plasma effluents external to processing chamber **307**. Plasma effluents produced in remote plasma source **305** may include a variety of reactive and nonreactive species that may include one or more precursors including argon, helium, hydrogen, nitrogen, and additional inert or reactive precursors. Once generated by remote plasma source **305**, the effluents may be delivered to the processing chamber through an inlet assembly coupling the remote plasma source with the top plate **310** of the semiconductor processing chamber **307**.

The inlet assembly may include a mounting assembly which may have at least two components in disclosed embodiments. A first component of an exemplary mounting assembly may include a gas block **315** which at least partially defines a central distribution channel **303** through which plasma effluents and/or precursors may be delivered to processing chamber **307**. Gas block **315** may be annular in shape and may include extended support sections **317** that may provide both an increased mating platform as well as improved structural support for a larger power supply such as remote plasma source **305**. A second component of the mounting assembly may include mounting block **325** further defining at least a portion of the central distribution channel **303** of the inlet assembly. Mounting block **325** may include a first mounting surface **326** and a second mounting surface **327** opposite the first mounting surface **326**. In embodiments, mounting block **325** may also include extended support sections **328** providing both an increased mating platform as well as improved structural support.

Portions of mounting block **325** may define multiple sections of central distribution channel **303**, and may define similar or different shapes of the channel from each other. For example, a first section **330** of mounting block **325** may define a first section of the central distribution channel **303** extending from the first mounting surface **326** to an intermediate portion of mounting block **325**. In embodiments the first section **330** of mounting block **325** may be characterized by a cylindrical shape, or the section may be characterized by a first diameter. A second section **335** of mounting block **325** may be characterized by a similar or different shape than first section **330** of mounting block **325**. In embodiments, second section **335** of mounting block **325** may define a second section of central distribution channel **303** extending from the intermediate portion of mounting block **325** to the second mounting surface **327**. Second section **335** of mounting block **325** may be characterized by a conical shape, or may be characterized by an increasing diameter at least partially along the intermediate portion of mounting block **325** to the second mounting surface **327**.

The inlet assembly coupling the remote plasma source with the top plate **310** may further include a precursor distribution assembly **320** defining a plurality of distribution channels fluidly coupled with an injection port **322**, which may be a single injection port in disclosed embodiments. As illustrated, injection port **322** may be fluidly coupled with a precursor injection line **324** configured to provide precursors which may bypass remote plasma source **305**. Precursor distribution assembly **320** will be discussed in greater detail below with reference to FIGS. **4**A-4B. Precursor distribution assembly **320** may include a first surface **321** which may be coupled with gas block **315**. Precursor distribution assembly **320** may further include a second surface **323** opposite first surface **321** and coupled with mounting block **325**. In this way, the two components of the mounting assembly may be spatially separated by the precursor distribution assembly **320**.

Mounting block **325** may be coupled with processing chamber **307** in a variety of ways, one embodiment of which is illustrated in FIG. **3**. Top plate **310** may include a first surface **309** in which an opening **312** is defined. Top plate **310** may also include a second surface **311** opposite the first surface **309**. Opening **312** may be defined in top plate **310** from upper surface **309** to a lower surface **314** of opening **312**. Top plate **310** may further define a plurality of outlet distribution channels **316** defined from the lower surface **314** of opening **312** to the second surface **311** of top plate **310**, providing fluid communication with processing chamber **307**. Outlet distribution channels **316** may be distributed through top plate **310** in a variety of patterns and may be configured to provide a more uniform flow into processing chamber **307**. Within opening **312**, top plate **310** may further define a ledge **313** on which mounting block **325** may be seated. Within ledge **313** one or more o-rings **340** may be included to provide a seal between the inlet assembly via mounting block **325** and chamber **307** via top plate **310**.

Many conventional power supplies utilized in plasma generation may provide power down below 100 kHz, 10 kHz, or less. Such power supplies often have a smaller footprint along with a lower weight of the electrical source itself. Modifying the system to accommodate the remote plasma source **305** may require significant modifications to the inlet assembly to accommodate not only the larger size, but also the increased weight of the supply itself. Embodiments of the present technology may be specifically configured to accommodate such a remote plasma source as will be described in detail herein.

In order to accommodate the increased size and weight of the high-frequency electrical source **305**, semiconductor processing system **300** may further include support assembly **350** in order to properly balance and support remote plasma source **305**. The support assembly **350** may include any number of mounting plates or other structural devices in order to provide such balance and support. Support assembly **350** coupled with the remote plasma source **305** may additionally include floating supports **355** that may provide further support in stabilization during system operation. In embodiments the support assembly may include at least one, e.g. 1, 2, 3, 4, 8, 12, 20, etc. or more, support extension **355** extending from the support assembly **350** towards top plate **310**. Support extensions **355** may include a variety of shapes configured for bearing the weight of remote plasma source **305**, and as illustrated in FIG. **3**, may include an S-shape in disclosed embodiments.

Support extensions **355** may be separated from top plate **310** in a first operational position in disclosed embodiments. Such a first operational position is illustrated in FIG. **3** and shows a gap between the support extensions **355** and top plate **310**. Although illustrated as a defined gap in FIG. **3**, it is to be understood that the first operational position may include any degree of spacing between the support extensions **355** and top plate **310** including a first degree of contact between the structures. Support extensions **355** may be utilized and configured to contact top plate **310** in a second operational position engageable during a processing operation.

As previously discussed, o-rings **340** may be used in the coupling of mounting block **325** with top plate **310**, and may aid in reducing leakage during operation, which may occur under vacuum conditions. Compression of o-rings **340** may occur both from vacuum conditions as well as from the weight of remote plasma source **305**. In such case, o-rings **340** may compress to an extent to allow support extensions **355** to engage top plate **310** of chamber **307** in the discussed second operational position. In a situation in which support extensions **355** contact top plate **310** in the first operational position, the second operational position may be differentiated from the first operational position by a second degree of contact between the support extensions **355** and top plate **310**. In such a situation the second degree of contact may be greater or at a higher force than the first degree of contact, and may be due at least in part to vacuum conditions enacted during a processing operation. Support extensions **355** may then in turn reduce strain on the inlet assembly components as well as aid in reducing vibration during operation.

Turning to FIGS. **4**A and **4**B, shown are schematic cross-sectional views of a portion of an exemplary precursor distribution assembly **400** according to the disclosed technology, which includes a detailed view of an embodiment of precursor distribution assembly **320** previously described. As illustrated in FIGS. **4**A-**4**B, the precursor distribution assembly **400** may include one or more plates, such as two plates **405**, **450** as illustrated, and may include an annular shape defining at least a portion of the central distribution channel. In embodiments the precursor distribution assembly **400** may include up to or more than 1, 2, 3, 4, 5, 7, 10, etc. or more plates coupled together to produce the precursor distribution assembly **400**. As illustrated, the figures show a view of the precursor distribution assembly from the position of a remote plasma source, such as remote plasma source **305** previously described, and including a view of outlet distribution channels **498**, or in disclosed embodiments apertures of a baffle plate or showerhead included within a processing chamber. In disclosed embodiments the precursor distribution assembly **400** may include at least two coupled plates, which at least partially define a plurality of distribution channels as will be described below.

FIG. **4**A illustrates a view of a first plate **405** which may be located proximate a gas block, such as gas block **315** previously described. First plate **405** may be annular in shape including an inner diameter **407** and an outer diameter **408**. First plate **405** may additionally define at least a portion of a central distribution channel **409** which may be similar to the central distribution channel **303** previously described. In disclosed embodiments first plate **405** may be characterized by shapes other than an annular shape.

First plate **405** may define an inlet port **410**, which may be similar to the precursor injection port **322** previously described. Inlet port **410** may provide access to a fluid delivery channel **412** also defined in first plate **405**. When coupled with a precursor source, such a configuration may provide a way in which the precursor may be distributed to a processing chamber while bypassing a remote plasma source. Delivery channel **412** may be fluidly coupled with a first distribution channel **415** defined between the inner diameter **407** and outer diameter **408**, and extending tangentially from delivery channel **412** and injection port **410**. First distribution channel **415** may at least partially extend about an interior circumference of first plate **405**. In embodiments first distribution channel **415** extends bidirectionally about such a circumference from delivery channel **412**, and may extend up to a full circumference of the interior circumference. As illustrated in FIG. **4**A, first distribution channel **415** may extend partially about the interior circumference, and may extend up to about 25%, about 50%, about 75%, or any other percent up to 100%

of the full circumference. In embodiments first distribution channel **415** may extend about 50% of an interior circumference, or about 25% in each direction from delivery channel **412**, before extending to at least two secondary distribution channels **420**, **430**.

Secondary distribution channels **420**, **430** may extend in a similar or different fashion than the first distribution channel **415** from delivery channel **412**. As illustrated, secondary distribution channels **420**, **430** may extend bidirectionally from distal portions of first distribution channel **415** about a second interior circumference of first plate **405** that is smaller than the first interior circumference. Secondary distribution channels **420**, **430** may extend partially about the second interior circumference, and may extend up to about 25%, about 50%, about 75%, or any other percent up to 100% of the full second interior circumference. In one embodiment as illustrated in FIG. **4**A, secondary distribution channels **420**, **430** each extend less than about 30% of the full circumference of the second interior circumference.

Each secondary distribution channel **420**, **430** may extend about the second interior circumference to two positions, such as positions **422**, **424** as illustrated for second distribution channel **420**. The secondary distribution channels may extend tangentially from first distribution channel **415** to at least two tertiary distribution apertures, such as apertures **425**A, **427**A as illustrated in FIG. **4**A for secondary distribution channel **420**. The tertiary distribution apertures may be located at distal portions of the secondary distribution channels, and may be proximate the end positions, such as proximate positions **422**, **424** as illustrated. The tertiary distribution apertures may be at least partially defined by top plate **405**, and may provide access to second plate **450**. Although circumference is used in reference to a generally circular shape, it is understood that alternative geometries may be used for the distribution channels, and circumference may generally refer to a perimeter of such geometries.

FIG. **4**B illustrates a view of a second plate **450** which may be located proximate a mounting block, such as mounting block **325** previously described. Second plate **450** may be annular in shape including an inner diameter **452** and an outer diameter **454**. Second plate **450** may additionally define at least a portion of a central distribution channel **456** which may be similar to the central distribution channel **303** previously described. In disclosed embodiments second plate **450** may be characterized by shapes other than an annular shape.

Second plate **450** may at least partially define a portion of at least two tertiary distribution apertures **425**B, **427**B, which may provide fluid communication between first plate **405** and second plate **450** via the coupled tertiary distribution apertures, which may be partially defined by each plate. Second plate **450** may also at least partially define at least two tertiary distribution channels extending from the at least two tertiary distribution apertures. As illustrated in FIG. **4**B, four tertiary distribution channels **432**, **434**, **436**, **438** are illustrated extending into a third interior circumference that may be equal to, greater than, or less than the second interior circumference. Each tertiary distribution channel may extend bidirectionally from a tertiary distribution aperture about the third interior circumference. Each tertiary distribution channel may extend partially about the third interior circumference, and may extend up to about 25%, about 50%, about 75%, or any other percent up to 100% of the full third interior circumference. In disclosed embodiments, each tertiary distribution channel extends less than about 25% of the third interior circumference,

Second plate **450** may further define at least two quaternary distribution channels extending from the at least two tertiary distribution channels. As illustrated in FIG. **4**B, second plate **450** defines at least one quaternary distribution channel **440** extending from each tertiary distribution channel, and in embodiments a plurality of quaternary distribution channels **440** extend from each tertiary distribution channel. Quaternary distribution channels **440** may extend to inner diameter **452** and provide access to the at least partially defined central distribution channel **456**. Accordingly, as illustrated in the two schematics the precursor distribution assembly **400** may define a plurality of distribution channels fluidly coupled with a single injection port, where the precursor distribution assembly includes at least two annular plates coupled with each other and at least partially defining a central distribution channel.

A first plate of the at least two annular plates may define a fluid injection port as well as a first distribution channel tangentially extending from this injection port. A second plate of the at least two annular plates defines at least two secondary distribution channels, such as the tertiary and quaternary distribution channels discussed, where the secondary distribution channels are in fluid communication with the first distribution channel and the central distribution channel to provide an injected fluid substantially uniformly to the central distribution channel. This distribution configuration may provide a number of benefits over conventional schemes. For example, precursor mixing between a radicalized precursor provided by a remote plasma source and a non-radicalized precursor provided through the injection port of the precursor distribution assembly may occur prior to the precursors entering the processing chamber. In this way, less recombination may occur from the radicalized species because of the shorter flow path provided by this design. Additionally, the precursor distribution assembly may provide improved and more uniform interaction between the precursors based on the distribution channels within the precursor distribution assembly providing the injected precursor more uniformly across the central distribution channel.

FIG. **5** shows a method **500** of etching that may reduce film contamination and provide more uniform precursor distribution according to the present technology. Method **500** may be performed in any of the systems previously described and may include optional operations including delivering a precursor for ionization to a remote plasma source. Method **500** may include generating a plasma within a remote plasma source to create plasma effluents of the first precursor in operation **510**. The remote plasma source may operate in a variety of plasma powers including up to 1000 Watts, 6000 Watts, 8000 Watts, 10,000 Watts, etc. or more. Method **500** may further include bypassing the remote plasma source with a second precursor flowed into a gas distribution assembly at operation **520**. The gas distribution assembly may be fluidly coupled with a remote plasma source, such as via a central distribution channel.

Method **500** may also include contacting the second precursor with the plasma effluents of the first precursor to produce an etching formula at operation **530**. Contacting the precursors may occur externally to a processing chamber in which the etching may be performed, such as in the central distribution channel. At operation **540**, after allowing the precursors to interact, the etching formula may be flowed into a processing chamber in which a substrate may be housed, and materials on the substrate may be etched with the etching formula. By forming the plasma and plasma effluents externally to the processing chamber, degradation of chamber components or coatings may be reduced or prevented in embodiments. The sputtered particles may be carried through the system and deposited on the substrate being worked, which may result in short-circuiting or failure of the produced device. Accordingly, by utilizing the described methods increased device quality may be provided as well as increased chamber component life. Additionally, by utilizing a gas distribution assembly or precursor distribution assembly, such as those discussed previously, the methods may provide a more uniform distribution of the etching formula due to improved interaction and mixing provided in the central distribution channel. Consequently, more uniform etching may be performed on materials on the substrate, which may improve overall device quality.

In the preceding description, for the purposes of explanation, numerous details have been set forth in order to provide an understanding of various embodiments of the present technology. It will be apparent to one skilled in the art, however, that certain embodiments may be practiced without some of these details, or with additional details.

Having disclosed several embodiments, it will be recognized by those of skill in the art that various modifications, alternative constructions, and equivalents may be used without departing from the spirit of the embodiments. Additionally, a number of well-known processes and elements have not been described in order to avoid unnecessarily obscuring the present technology. Accordingly, the above description should not be taken as limiting the scope of the technology.

Where a range of values is provided, it is understood that each intervening value, to the smallest fraction of the unit of the lower limit, unless the context clearly dictates otherwise, between the upper and lower limits of that range is also specifically disclosed. Any narrower range between any stated values or unstated intervening values in a stated range and any other stated or intervening value in that stated range is encompassed. The upper and lower limits of those smaller ranges may independently be included or excluded in the range, and each range where either, neither, or both limits are included in the smaller ranges is also encompassed within the technology, subject to any specifically excluded limit in the stated range. Where the stated range includes one or both of the limits, ranges excluding either or both of those included limits are also included.

As used herein and in the appended claims, the singular forms "a", "an", and "the" include plural references unless the context clearly dictates otherwise. Thus, for example, reference to "an aperture" includes a plurality of such apertures, and reference to "the plate" includes reference to one or more plates and equivalents thereof known to those skilled in the art, and so forth.

Also, the words "comprise(s)", "comprising", "contain(s)", "containing", "include(s)", and "including", when used in this specification and in the following claims, are intended to specify the presence of stated features, integers, components, or operations, but they do not preclude the presence or addition of one or more other features, integers, components, operations, acts, or groups.

The invention claimed is:

1. A semiconductor processing system comprising:

a remote plasma source;

a processing chamber having a top plate having a first surface, and defining a recess within the first surface; and

an inlet assembly coupling the remote plasma source with the top plate and comprising:

a precursor distribution assembly defining a plurality of distribution channels fluidly coupled with an injection port, and

a mounting assembly comprising:

a gas block coupled between the remote plasma source and the precursor distribution assembly, and

a mounting block coupled between the precursor distribution assembly and the top plate, wherein the mounting block extends past the first surface of the top plate to couple with the top plate within the recess.

2. The semiconductor processing system of claim **1**, wherein the mounting block defines a channel and comprises a first mounting surface and a second mounting surface opposite the first mounting surface.

3. The semiconductor processing system of claim **2**, wherein a first section of the channel extending from the first mounting surface is characterized by a first diameter.

4. The semiconductor processing system of claim **3**, wherein a second section of the channel extending from the first section of the channel to the second mounting surface is characterized by an increasing diameter at least partially along the first section of the channel towards the second mounting surface.

5. The semiconductor processing system of claim **2**, wherein the gas block is coupled with a first surface of the precursor distribution assembly and the mounting block is coupled with a second surface of the precursor distribution assembly opposite the first surface of the precursor distribution assembly.

6. The semiconductor processing system of claim **1**, wherein the precursor distribution assembly comprises an annular shape.

7. The semiconductor processing system of claim **1**, wherein the precursor distribution assembly comprises at least two coupled plates, which at least partially define the plurality of distribution channels.

8. The semiconductor processing system of claim **7**, wherein a first plate of the at least two coupled plates at least partially defines a first distribution channel extending tangentially from the injection port to at least two secondary distribution channels.

9. The semiconductor processing system of claim **8**, wherein the at least two secondary distribution channels extend tangentially from the first distribution channel to at least two tertiary distribution apertures.

10. The semiconductor processing system of claim **9**, wherein a second plate of the at least two coupled plates at least partially defines a portion of the at least two tertiary distribution apertures, and wherein the second plate further defines at least two tertiary distribution channels extending from the at least two tertiary distribution apertures.

11. The semiconductor processing system of claim **10**, wherein the second plate further defines at least two quaternary distribution channels extending from the at least two tertiary distribution channels.

12. The semiconductor processing system of claim **1**, wherein the recess extends within the top plate past a ledge further defined within the recess by the top plate, and wherein the mounting block is coupled with the ledge.

13. The semiconductor processing system of claim **12**, wherein the top plate comprises a second surface opposite the first, wherein the recess is defined at least partially by the first surface of the top plate and a lower recess surface, and wherein a plurality of outlet channels are defined by the top plate between the lower recess surface and the second surface of the top plate.

14. The semiconductor processing system of claim **1**, further comprising:

a stabilization plate having a first surface coupled with the remote plasma source, and a second surface opposite the first; and

at least one support leg extending from the second surface of the stabilization plate towards the top plate.

15. The semiconductor processing system of claim **14**, further comprising a gap between the at least one support leg and the top plate.

16. A semiconductor processing system comprising:

a remote plasma source;

a processing chamber having a top plate;

an inlet assembly coupling the remote plasma source with the top plate and comprising:

a precursor distribution assembly defining a plurality of distribution channels fluidly coupled with a single injection port, wherein the precursor distribution assembly comprises at least two annular plates coupled with each other and at least partially defining a central distribution channel, wherein a first plate of the at least two annular plates defines the single injection port and a first distribution channel tangentially extending from the single injection port, and wherein a second plate of the at least two annular plates defines at least two secondary distribution channels in fluid communication with the first distribution channel and the central distribution channel, and

a mounting assembly, wherein the mounting assembly comprises at least two components spatially separated by the precursor distribution assembly, wherein the at least two components include a first component positioned between and contacting each of the remote plasma source and the precursor distribution assembly, and a second component positioned between and contacting each of the precursor distribution assembly and the top plate; and

a support assembly coupled with the remote plasma source and including at least one support extension extending from the support assembly towards the top plate, wherein the at least one support extension is separated from the top plate in a first operational position, and wherein the at least one support extension is configured to contact the top plate in a second operational position engageable during a processing operation.

17. A semiconductor processing system comprising:

a remote plasma source;

a processing chamber having a top plate defining at least a portion of a central distribution channel extending from the remote plasma source, wherein the central distribution channel extends past a first surface of the top plate and is fluidly coupled with a plurality of outlet distribution channels defined within the top plate; and

an inlet assembly coupling the remote plasma source with the top plate and comprising:

a precursor distribution assembly defining a portion of the central distribution channel and a plurality of internal channels fluidly coupled with an injection port,

an annular gas block coupled between the remote plasma source and the precursor distribution assembly, wherein the annular gas block defines at least a portion of the central distribution channel, and

a mounting block coupled between the precursor distribution assembly and the top plate, wherein the mounting block defines at least a portion of the central distribution channel.

* * * * *